GE 136B: Winter 2026 Field Guide

Owens Valley, Saline Valley & Northern Death Valley

A view of the Saline Valley Warm Springs, nestled in a remote corner of Death Valley National Park at 1,375 ft elevation and accessible only by roughly 35 miles of dirt road. The springs—ranging from 95°F to 107°F—sit within a sweeping basin framed by the Inyo Mountains to the west and the Last Chance Range to the east, surrounded by hot spring soaking tubs, desert oasis palms, and a rich tradition of backcountry community stretching back to the 1950s.

Instructor: Joe Kirschvink
TAs: Nick Anderson
Cover Photo: Dave’s Travel Corner

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Note: All times are approximate. Road conditions on Saline Valley and Racetrack roads must be verified before departure — check nps.gov/deva/planyourvisit/conditions.htm. Saline Valley accessible via North Pass (7,300 ft) or South Pass (5,997 ft); both may be closed after winter storms. Alternate Night 2: Mesquite Spring Campground (36.633°N, 117.027°W) — currently CLOSED due to Dec 2025 flood damage; confirm status before trip.

1. Schedule

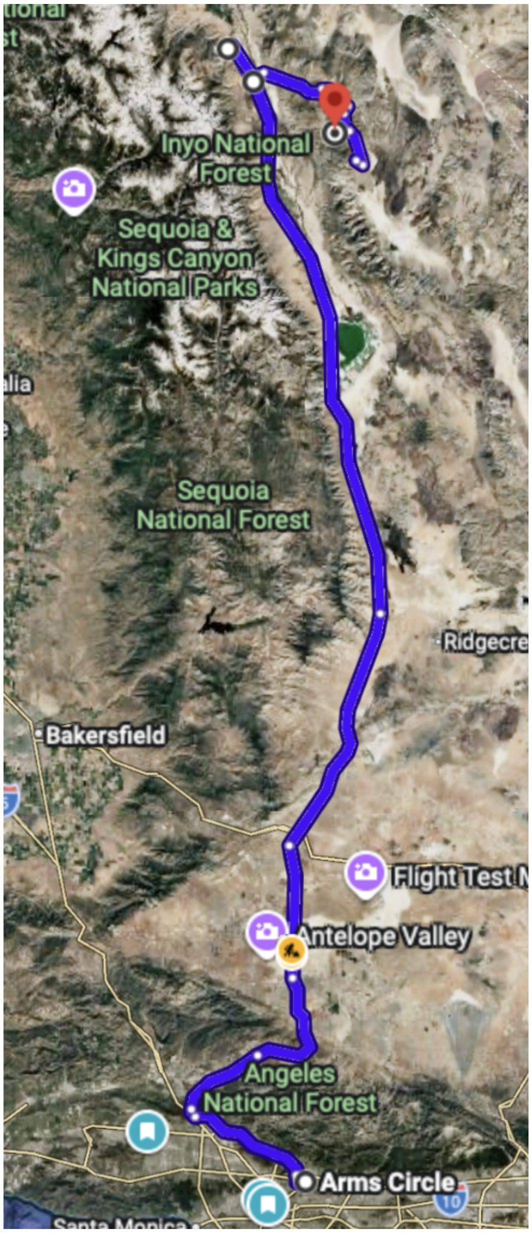
1.1 Field Trip Schedule — February 27 – March 1, 2026

Day	**Time**	**Stop**	**Coordinates**	**Talks**
Day 1 — Friday, February 27, 2026				
Day 1	6:30 AM	Depart Pasadena (Caltech)	34.1377, −118.1253	—
Day 1	∼9:30 AM	Lone Pine — fuel & restrooms	36.6069, −118.0626	—
Day 1	∼10:30 AM	**Keough's Hot Springs**	37.2547, −118.3769	Funaro: Basin & Range; Dworak: Sierra Nevada Glaciations; Ree: Magmatic History of the White-Inyo Range; Bednarick: Hunter Mountain Pluton; Thalhammer: Mining in the Inyo Mountains
Day 1	∼12:30 PM	**Waucoba Mountain**	37.0215, −118.0081	MacLean: Trilobite & Archaeocyathid Fossil Morphologies in the Saline Valley and Harkless Formations
Day 1	∼3:30 PM	Drive to Saline Valley via South Pass (4WD required)	—	—
Day 1	∼5:30 PM	**Saline Valley Warm Springs** — Night 1	36.8056, −117.7739	Ma: Geologic History of the Saline Valley Formation; Davis: Geochemistry of Saline Valley Warm Springs; Chastain: Saline Extremophiles; Vescu: Cenozoic Tectonics of Saline Valley; Keebler: Saline Valley; Shao: Flora of Saline Valley; Baldwin: Salt-Tolerant Microbes; Aguilar: Desert Plant Healing, Rituals & Material Culture; Westerkamp: O & H Isotopes of Great Basin Water; Sharples: History & Stories from Saline Valley Warm Springs; Kwiecinski: History of the Timbisha Shoshone; Tejas: Salt, Salt Tram & Borax Mining in Saline Valley
Day 2 — Saturday, February 28, 2026				
Day 2	7:00 AM	Breakfast; pack up camp	—	—
Day 2	∼8:00 AM	**Eureka Dunes**	37.0997, −117.6712	Sonic Sands
Day 2	∼10:30 AM	**Ubehebe Crater**	37.0105, −117.4525	Hannahs: Red Cathedral Formation
Day 2	∼11:30 AM	**Scotty's Castle** (exterior)	37.0128, −117.3983	Yoshioka: Scotty's Castle
Day 2	∼1:00 PM	**Racetrack Playa** via Teakettle Junction (4WD, ∼27 mi dirt)	36.6828, −117.5597	Williams: Racetrack Playa and Sliding Rocks
Day 2	∼6:30 PM	**Stovepipe Wells Campground** — Night 2	36.6079, −117.1481	Raecke: Observable Constellations; Sanchez: Tungsten and Darwin, CA
Day 3 — Sunday, March 1, 2026				
Day 3	7:00 AM	Breakfast; break camp	—	—
Day 3	∼11:00 AM	**Trona Pinnacles**	35.6197, −117.3706	—
Day 3	∼12:00 PM	**Searles Lake / Borax Site**	35.7397, −117.3550	McCann: Geochemistry in Searles Valley; Tran: Boron Geochemical Cycle
Day 3	∼2:00 PM	Depart for Pasadena via CA-178 / I-15	—	—
Day 3	∼8:00 PM	Arrive Caltech	34.1377, −118.1253	—

2. Routes

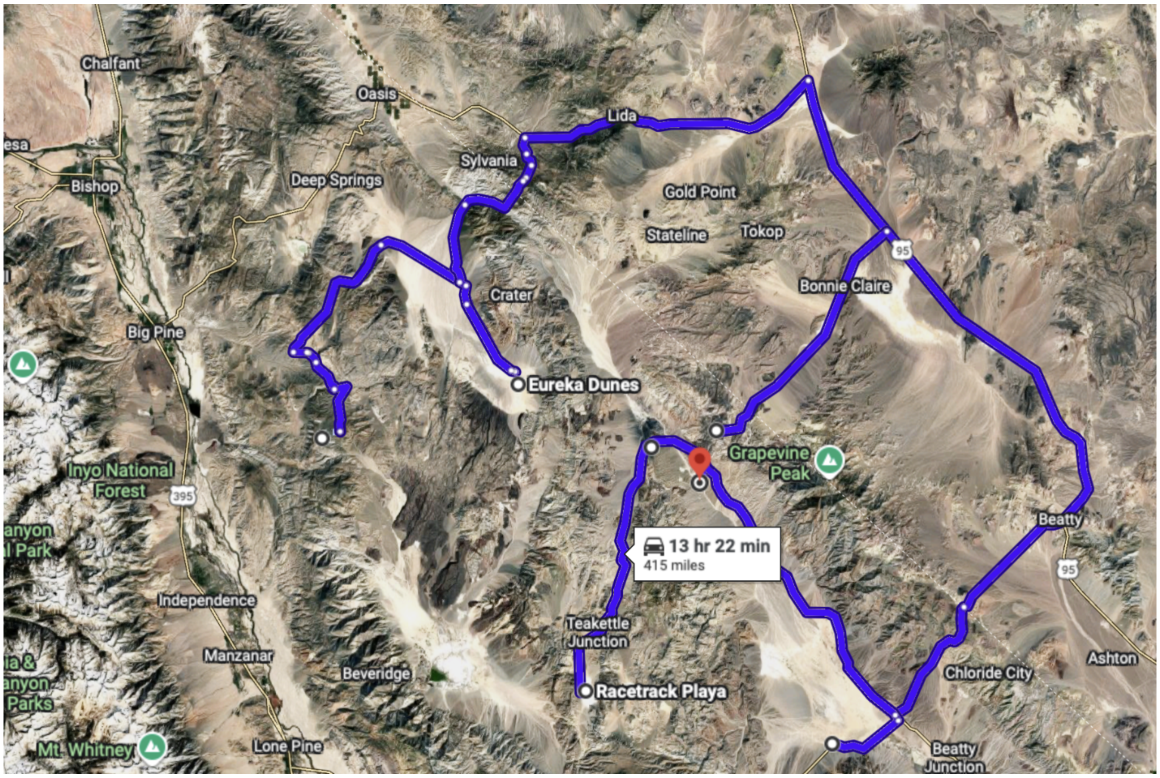
2.1 Day 1: Friday February 27, 2026 — Pasadena to Saline Valley

Route Summary: Pasadena → US-395 N → Lone Pine → Big Pine (Keough's Hot Springs) → Waucoba Mountain area → South Pass / Saline Valley Road → Saline Valley Warm Springs. Total ≈329 miles, 7.5 hours driving plus stops.


Inyo National Forest
Sequoia & Kings Canyon National Parks
Sequoia National Forest
Ridgecre
Bakersfield
Flight Test M
Antelope Valley
Angeles National Forest
Arms Circle
Santa Monica
10

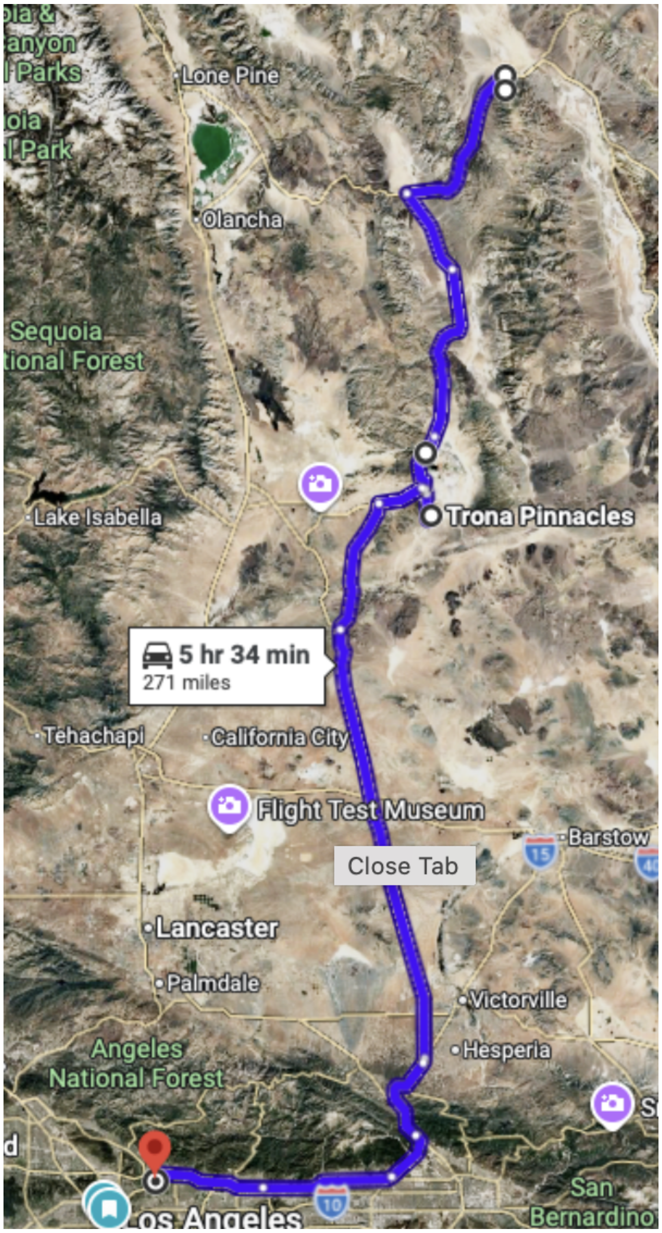
2.2 Day 2: Saturday February 28, 2026 — Saline Valley to Stovepipe Wells

Route Summary: Saline Valley Warm Springs → Eureka Dunes → Ubehebe Crater → Scotty's Castle → Racetrack Playa → Stovepipe Wells Campground. Total ≈415 miles on mixed dirt and paved roads; allow 13+ hours including stops.


Chalfant
Oasis
Lida
Sylvania
Bishop
Deep Springs
Gold Point
Stateline
Tokop
95
Bonnie Claire
Crater
Big Pine
Eureka Dunes
Grapevine Peak
Inyo National Forest
395
Beatty
13 hr 22 min
415 miles
95
Independence
Teakettle Junction
Manzanar
Beveridge
Racetrack Playa
Ashton
Chloride City
Mt. Whitney
Lone Pine
Beatty Junction

2.3 Day 3: Sunday March 1, 2026 — Stovepipe Wells to Pasadena

Route Summary: Stovepipe Wells → CA-190 W → Trona Pinnacles → Searles Lake / Borax Discovery Site → CA-178 / I-15 → Pasadena. Total ≈266 miles, ≈5.5 hours driving plus stops.


Lone Pine
Olancha
Sequoia National Forest
Lake Isabella
Trona Pinnacles
5 hr 34 min
271 miles
Tehachapi
California City
Flight Test Museum
Close Tab
Barstow
15
Lancaster
Palmdale
Victorville
Hesperia
Angeles National Forest
San Bernardino
10
Los Angeles

3. Useful Information

3.1 Emergency Contacts

- **Trip Leaders:** Nick Anderson (415) 500-5307; Joe Kirschvink (213) 248-3422; Sophia Westercamp (719) 648-5461
- **Caltech Safety Office:** (626) 395-5000
- **GPS Division Satellite Phones:** 881651455634; 881622445739
- **Northern Inyo Hospital** (Bishop): 150 Pioneer Ln, Bishop, CA 93514 — (760) 873-5811
- **Southern Inyo Healthcare District** (Lone Pine): 501 E Locust St, Lone Pine, CA 93545 — (760) 876-5501
- **Beatty Medical Center** (NV): 250 S Irving St, Beatty, NV 89003 — (775) 990-1414
- **Death Valley NPS Visitor Center** (Furnace Creek): (760) 786-3200
- **Road conditions:** nps.gov/deva/planyourvisit/conditions.htm

Cell Coverage: Verizon and T-Mobile have decent coverage in Owens Valley (US-395 corridor) and at Stovepipe Wells. There is **no cell service** at Saline Valley Warm Springs, Racetrack Playa, or Mesquite Spring. The GPS Division satellite phone will be carried at all times.

3.2 Saline Valley Warm Springs Campground (Primitive)

Location: Saline Valley, Death Valley National Park (36.8056°N, 117.7739°W); elevation ∼1,375 ft.

Overview: Saline Valley Warm Springs is one of the most remote and storied backcountry destinations in Death Valley National Park, approximately 35 miles from the nearest paved road. The site has been a gathering place since prehistoric times and developed as a recreational hot spring community beginning in the 1950s, becoming part of Death Valley National Park in 1994. The springs range from 95–117°F and feed user-developed concrete soaking tubs at three spring areas: Lower Spring (Palm Spring), Middle Spring, and Upper Spring. Pools are cleaned daily by volunteers.

Campground Information:

- **Type:** Primitive backcountry (no formal NPS development)
- **Sites:** Dispersed; designated car-camping and walk-in zones
- **Reservations:** None — first-come, first-served
- **Fee:** No camping fee (NPS entrance fee applies)
- **Stay Limit:** 30 days per calendar year
- **Restrooms:** Vault toilets
- **Water: None** — bring all drinking water
- **Hookups:** None
- **Cell Service:** None
- **Generators:** 7:00 AM – 7:00 PM only
- **Quiet Hours:** No drums/amplified music after 10:00 PM

Campground Regulations:

- **Camping Zones:** No camping within 100 ft of source springs
- **Fires:** Community fire pit at Lower Spring. Bring firewood — no gathering on NPS land
- **Clothing:** Clothing-optional site; lewd behavior prohibited
- **Pets:** Leashed ($\leq$6 ft), attended; keep away from pools
- **Waste:** Pack out all trash; liquid waste at sanitary stations only
- **Wildlife:** Wild burros and coyotes present — **never leave food unattended**
- **Hot Springs:** Rinse before every entry; no soap in or near pools
- **Firearms/Fireworks:** Not permitted in Death Valley NP

Access & Navigation:

- **Vehicle:** High-clearance required; 4WD likely necessary; all-terrain tires strongly recommended; ∼35 miles unmaintained dirt road
- **North Pass:** From Big Pine via Waucoba/Death Valley Rd then Saline Valley Rd over North Pass (7,300 ft) — shorter but may be snow/ice-closed in winter
- **South Pass:** From Panamint Springs via Saline Valley Rd over South Pass (5,997 ft) — primary winter route
- **WARNING:** Do NOT use Google/Apple Maps — verify road conditions at nps.gov/deva/planyourvisit/conditions.htm before departure
- **Gas:** Big Pine (∼55 mi, ∼3 hrs) or Stovepipe Wells (∼97 mi, ∼4 hrs) — fill up completely before entering
- **Flat Tires:** Rocky road makes flats common — carry at least one full-size spare; a second is strongly recommended

3.3 Stovepipe Wells Campground

Location: Stovepipe Wells, Death Valley National Park (36.607807°N, 117.148063°W); elevation sea level (0 ft). On CA-190, ∼24 miles west of Furnace Creek.

Overview: A large, open campground adjacent to Stovepipe Wells village (general store, gas station, ranger station, restaurant, hotel). Sits at the edge of the Mesquite Flat Sand Dunes with views across Death Valley to the Panamint Range. Centrally located for exploring both northern and southern Death Valley.

Campground Information:

- **Sites:** 190 total; 28 tent-only (perimeter, with fire grates & picnic tables)
- **Reservations:** None — first-come, first-served; pay at automated station at entrance
- **Fee:** ∼$14/night (verify at pay station); no hookups
- **Season:** ∼October through April; verify before trip
- **Restrooms:** Flush toilets
- **Water:** Potable water on-site
- **Dump Station:** Available
- **Showers:** Not at campground; shower passes ∼$5/person at adjacent hotel (includes pool access)
- **Cell Service:** Verizon & AT&T functional (limited data); T-Mobile roaming
- **Wi-Fi:** Free in hotel lobby across the road
- **Generators:** 7:00 AM – 7:00 PM only
- **Quiet Hours:** 10:00 PM – 6:00 AM

Campground Regulations:

- **Campfires:** Allowed in provided fire grates; no wood gathering; fires must not be left smoldering or unattended; no trash in fire grate
- **Pets:** Leashed (≤6 ft) at all times; not allowed on trails beyond developed areas
- **Vehicles:** Max 1 RV with tow, 2 cars, or 4 motorcycles per site; max 8 people per site
- **Stay Limit:** 30 days maximum
- **Waste:** No dishwashing or bathing at water spigots or restrooms
- **Firearms/Fireworks:** Not permitted in Death Valley NP

Nearby Services (Stovepipe Wells Village):

- General store with food, supplies, camping gear
- Gas station (often cheapest fuel in Death Valley)
- Restaurant and bar
- NPS ranger station (backcountry permits)
- Hotel with swimming pool

Directions: From the CA-190 / Scotty's Castle Road junction, drive ∼9 miles east on CA-190. Campground is on the south side, clearly signed. Do not rely on navigation apps within the park.

3.4 Mesquite Spring Campground (Alternate — Night 2)

Location: Northern Death Valley NP (36.633°N, 117.027°W); elevation 1,800 ft. Off Scotty's Castle Road, 2 miles on a paved access road.

Overview: The northernmost developed campground in Death Valley NP; closest to Ubehebe Crater, Scotty's Castle, and Titus Canyon. At 1,800 ft it is noticeably cooler than the valley floor. 40 sites on paved roadways, each with picnic table and fire grate.

★ **CLOSURE NOTICE:** Mesquite Spring Campground sustained extensive damage from severe rain and flash flooding in late December 2025. As of February 2026, the campground remains **CLOSED** until repairs are complete. Check current status at nps.gov/deva/planyourvisit/conditions.htm before departure. Listed as **ALTERNATE Night 2 only** — use if reopened.

Campground Information (when open):

- **Sites:** 40 first-come, first-served; no reservations
- **Fee:** $20/night ($10 Senior/Access Pass); credit/debit at automated station
- **Restrooms:** Flush toilets; 1 ADA comfort station (center of campground)
- **Water:** Potable water on-site
- **Dump Station:** Available
- **Hookups:** None
- **Showers:** None
- **Cell Service:** None
- **Generators:** 7:00 AM – 7:00 PM; do not leave unattended
- **Quiet Hours:** 10:00 PM – 7:00 AM
- **Stay Limit:** 30 days; check-out 12:00 PM noon

Campground Regulations:

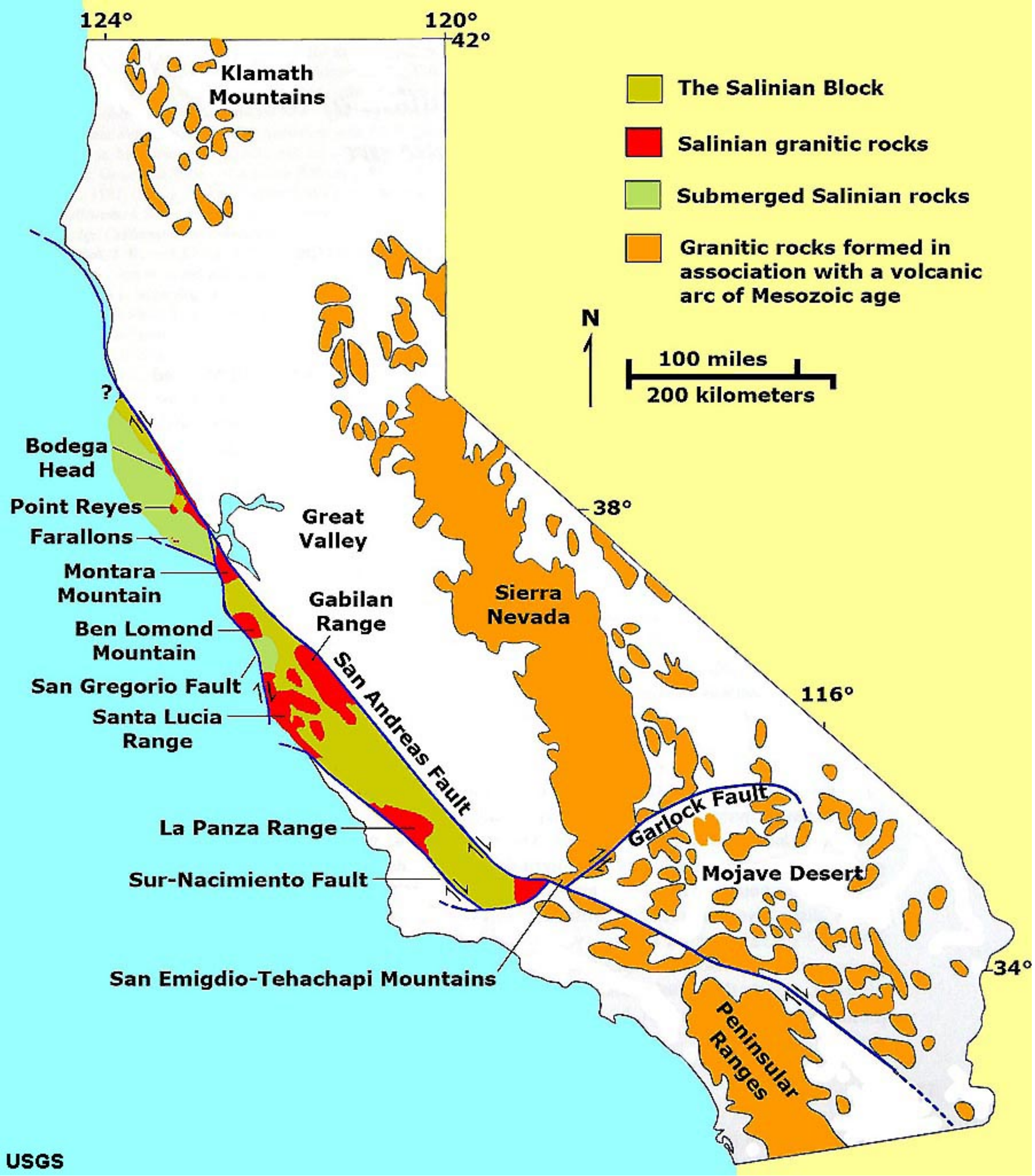
- **Campfires:** Wood fires in metal fire grates only; no wood gathering; no trash in grate; fires must not be left unattended; seasonal host may sell firewood
- **Pets:** Leashed ($\leq$6 ft); not left unattended; roads, campground, and developed areas only
- **Vehicles:** Max 1 RV with tow, 2 cars, or 4 motorcycles per site; max 8 people per site
- **Waste:** All liquid waste at sanitary stations only; no dishwashing at spigots or restrooms
- **Firearms/Fireworks:** Not permitted in Death Valley NP

Directions & Access:

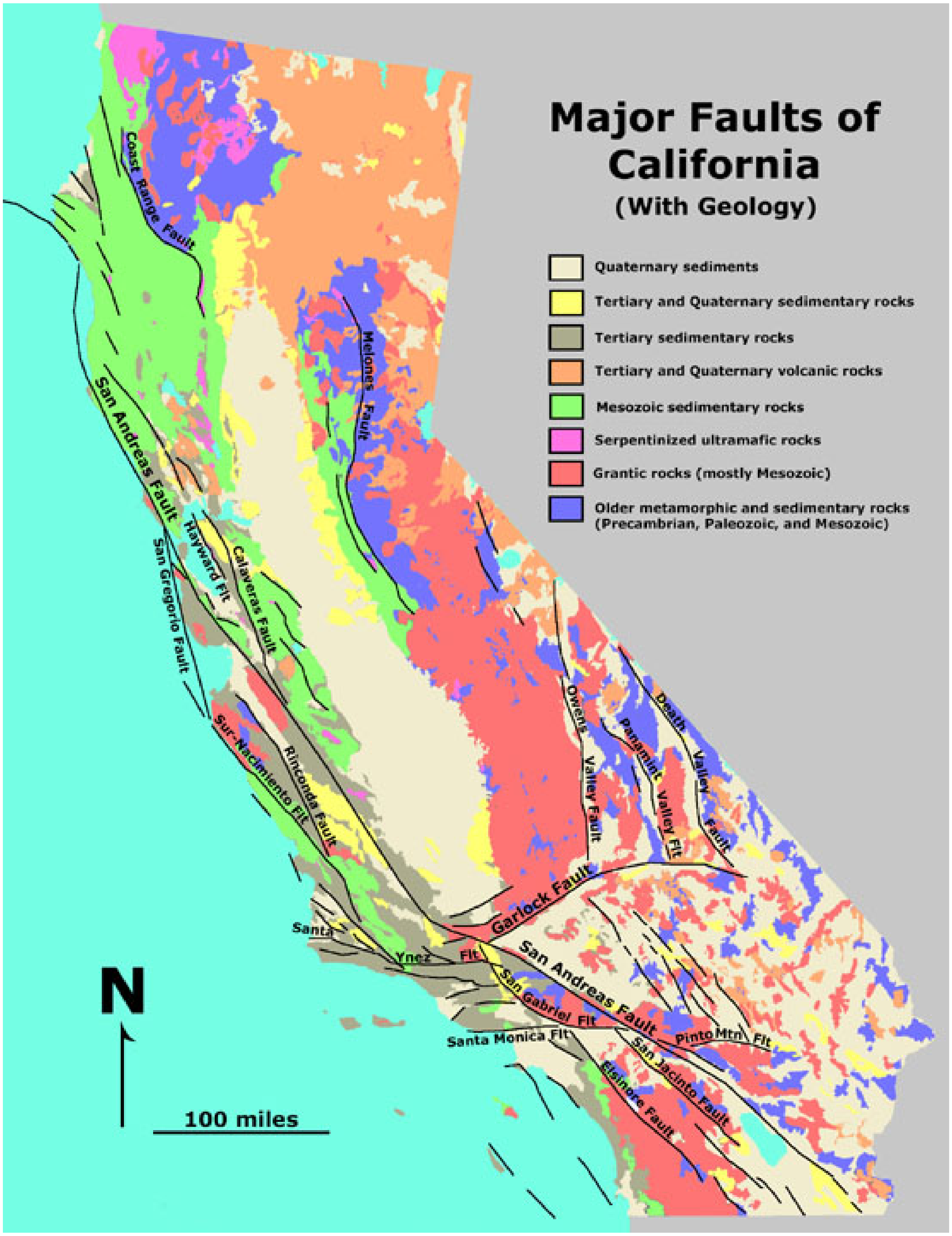
- From CA-190, take Scotty's Castle Road north 33 miles to access road junction; turn left, drive 2 miles to entrance
- Nevada Hwy 267 / Grapevine Canyon approach currently **closed** — CA-190 access only
- **Nearby:** Ubehebe Crater (5 mi N); Scotty's Castle; Titus Canyon; Marble Canyon

4. Maps

4.1 (1) Simplified Distribution of Granitic Basement in California


124°
120°
42°
Klamath Mountains
The Salinian Block
Salinian granitic rocks
Submerged Salinian rocks
Granitic rocks formed in association with a volcanic arc of Mesozoic age
N
100 miles
200 kilometers
?
Bodega Head
Point Reyes
Farallons
Montara Mountain
Ben Lomond Mountain
San Gregorio Fault
Santa Lucia Range
Great Valley
Gabilan Range
San Andreas Fault
Sierra Nevada
38°
116°
Garlock Fault
Mojave Desert
La Panza Range
Sur-Nacimiento Fault
San Emigdio-Tehachapi Mountains
34°
Peninsular Ranges
USGS

4.2 (2) Simplified Geologic Map of Faulting in California


Major Faults of California
(With Geology)
Quaternary sediments
Tertiary and Quaternary sedimentary rocks
Tertiary sedimentary rocks
Tertiary and Quaternary volcanic rocks
Mesozoic sedimentary rocks
Serpentinized ultramafic rocks
Grantic rocks (mostly Mesozoic)
Older metamorphic and sedimentary rocks (Precambrian, Paleozoic, and Mesozoic)
Coast Range Fault
Melones Fault
San Andreas Fault
Hayward Flt
Calaveras Fault
San Gregorio Fault
Sur-Nacimiento Flt
Rinconda Fault
Owens Valley Fault
Panamint Valley Flt
Death Valley Fault
Garlock Fault
Santa Ynez Flt
San Andreas Fault
San Gabriel Flt
Santa Monica Flt
Pinto Mtn Flt
San Jacinto Fault
Elsinore Fault
N
100 miles

5. Talks

5.1 (1) GE 136B Bingo and Word Search

G	O	B	I	N	G	O
name and view 5 constellations	conglomerate rock	horses and their allies	find a stromatolite	funny and/or interesting license plate	combine salt water, spring water, and bottled water	iron-bearing mineral
fault scarp	abandoned non-salt mine	saltgrass	bird	punch buggy no punchbacks	evidence of glacial activity	pass 4 distinct McDonalds arches
spot a shooting star	brecchia rock	trilobite fossil	take an aesthetic picture	pass 3 distinct signs w/ "saline"	recite a prayer at the red cathedral formation	non-halite evaporite mineral
carbonate mineral	Whoopsies car problems	creosote ring	Forget to bring sunscreen (free space)	identify 6 plants/small animals	trace fossil	meet other humans in the valley
license plates from 7 different states	lick salt at a salt mine	salt cedar tree	scorpion	joshua tree	Someone sets up tent wrong	form a rock band! (collect igneous, meta. and sedi. rocks)
spot a cybertruck	silicate mineral	lizard	alluvial fan	have a race at racetrack playa	conduct "business" at Schotty's Castle	ripple marks
mud cracks	evidence of volcanic activity	find one of Joe's drill holes	small mammal	roll a stone down a sand dune	conduct a healing ritual w/ desert plant	evidence of human activity (in valley)

Ge136 Word Search

```
Q O I H T H Z B J H V K T T H N C G V X H J U T O D E A W Q
B E F V K D R A Z I L Y P G E T I L O T A M O R T S D M S Q
G K N I V H C S R I K G C L Y M D H J O X Y H Q I P U R H G
P L W H P N R T V S Q O A I R G O N I M M S X Q K N O O O P
K O P X A I C C E R B L S Q T T Q M F O L I S S O F P I H N
D V U U F L J T A N M O B Y S A B L H E T X M Y F N R S C E
Z O A V Q T J T R B O E G P G N M Y F Y J A O G V Q N T C L
K T V K X D H L U H E G R Y L N F G E L D H K B B I P H P E
M O L Y L A E U S L Q I Z M L R B X A O M R R C D P O R L Z
I J S V I R A A M Z N O C K D V G S K M C I O P O R Z T B C
G O N Y R W L F S G W R I R I C A A T D P E N T O S S M G L
H Q I L M I I T D F S C V G V L Q T X J X H C G H A M I N E
N O I O V N N X R E V W N B I T K V L I H F R S C E B M D C
O Z R Z I F G O H S E I D N Y E K M R I P A V Y Z T R U Q N
I Y R M K R R N I M P P E M Z C B U I T P I T S S N N M C A
T E S D I E I B M M P V F C Q T C H I H B T G T T E F Z A F
A S N W F N T Z A L A A P Q I O E E I C O J T S P U U Q D L
L H U J U C U C H L A C B V S N R C T H B F X B B N D S Q J
L B N Q I H A J L C M U F U I I Y E C I Q L V W R O L O U F
E C P U I G L E W Q D Y Q U N C P S T S B X F X L V I V F T
T J U A S K Y N S Z E M M O N G E V R I C O T U Y B Z B Q K
S R J D G E I G E T I F L O R A F E I O R T L E A R U E S O
N D M J J E Z Z I N K T E N O H S O H S S O T I O J I T I U
O X E N G T L B E O C N M W T D N E T H V O P T R S Z I S C
C I M I J Y O R A W O T B N G M R O T T S W H A O T A L V Y
W F K V L L A D J Z I K M W R X K F F O P P Q C V L C A R Y
Q V P W I L Q R F N X T R F E L G W E F P Z J S Z E A H N Y
W M B R N L M H S I F P U P B D Q R Y Y E V N A O K L X L T
M A T J Y F K H Z J A Y A L P K C A R T E C A R K X D K L U
L P Q E D E O W B Q U E J Y W N P S G I T H N Z H M O B P M
```

1. salinevalley **2.** hotspring **3.** racetrackplaya **4.** schottycastle **5.** shoshone

6. healingritual **7.** darwinfrench **8.** trilobite **9.** dune **10.** halite **11.** trilobite

12. pupfish **13.** hydrothermal **14.** constellation **15.** tectonic **16.** fault **17.** orographic

18. creosote **19.** stromatolite **20.** breccia **21.** lizard **22.** evaporite **23.** magmatic

24. kirschvink **25.** geology **26.** camping **27.** fossil **28.** mineral **29.** mine **30.** flora

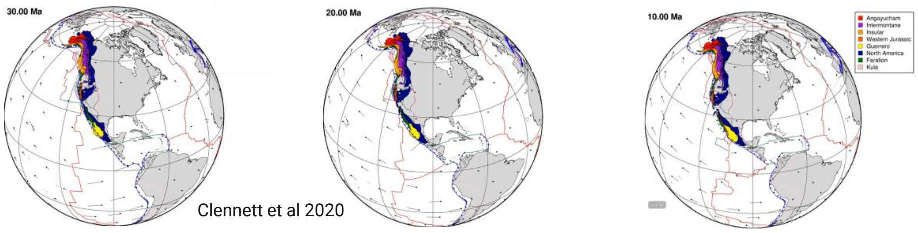
5.2 (2) Basin and Range

Basin and Range

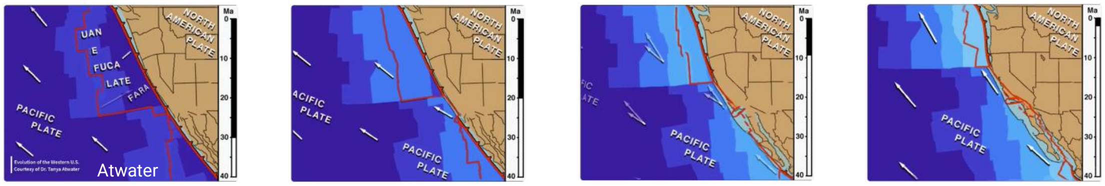
Eran Funaro

Basin
Range
Basin
Range
Basin
Range
Basin
Range
Basin
Range
Basin

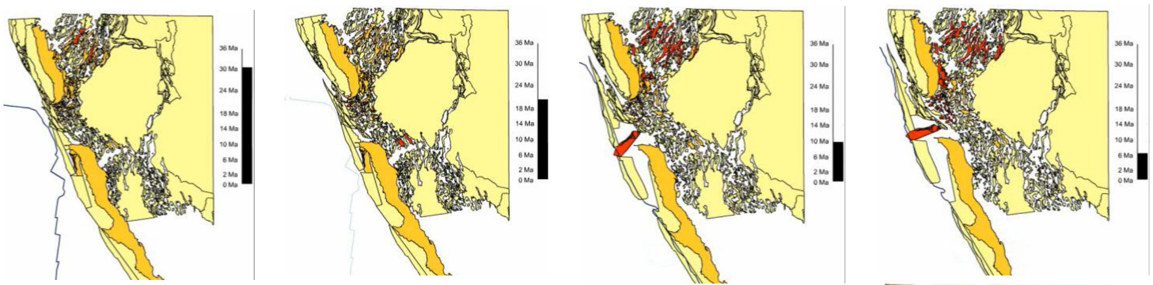
The Basin and Range is a massive geologic province covering much of the southwestern United States between the Sierra Nevada and the Colorado plateau. It is an example of a wide (failed) rift a continental divergent boundary where tensile deformation is spread out over a vast area. About 250 km of extension.


30.00 Ma
20.00 Ma
10.00 Ma
Angayucham
Intermontane
Insular
Western Jurassic
Guerrero
North America
Farallon
Kula

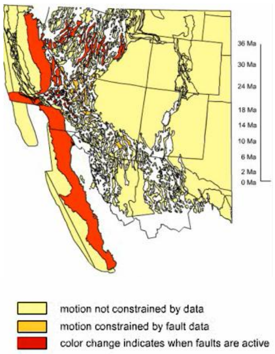
Clennett et al 2020


UAN
E
FUCA
LATE
FARA
NORTH AMERICAN PLATE
PACIFIC PLATE
Ma
0
10
20
30
40
Evolution of the Western U.S. Courtesy of Dr. Tanya Atwater

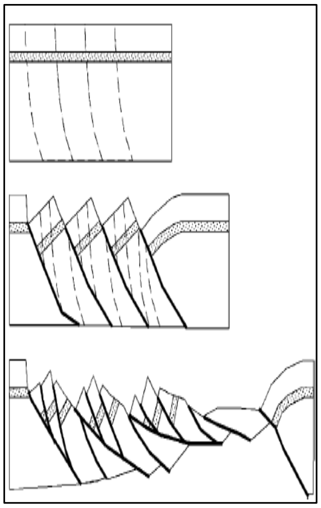
Atwater


36 Ma
30 Ma
24 Ma
18 Ma
14 Ma
10 Ma
6 Ma
2 Ma
0 Ma

The late Mesozoic to late Eocene the south-west experienced a compressional stress regime and crustal thickening. Around 20 Ma, at the late stages of the faralon plate subduction the Pacific Plate finally made direct contact with the North American Plate.
Unlike the Farallon Plate, which was pushing head-on, the Pacific Plate was moving toward the northwest marking the transformation of the western boundary of the North American plate from convergent to a divergent. Through the early and middle Miocene massive lengthening took place via detachment faults. Other mechanisms that contributed to the stretching were the weakening of the Basin and Range crust due to asthenospheric upwelling (slab window) heating it and leading to gravitational collapse of The overthickened crust causing its flow outward and self thinning.
At ~10Ma the Pacific plate motion direction turns northward, and the boundaries motion becomes more lateral. By 4Ma the right lateral motion takes over, and we get the mode of motion we know from modern day.


36 Ma
30 Ma
24 Ma
18 Ma
14 Ma
10 Ma
6 Ma
2 Ma
0 Ma
motion not constrained by data
motion constrained by fault data
color change indicates when faults are active

McQuarrie & Wernicke 2005



Detachment Faults

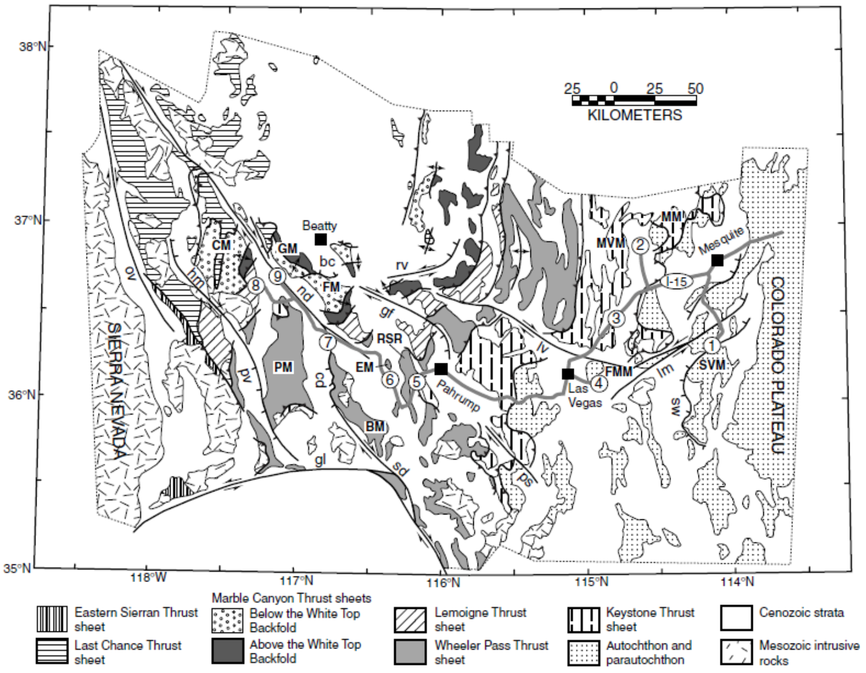
While typical normal faults occur at steep angles (around 60°), the extreme stretching in this province is accommodated by detachment faults (low-angle normal faults). These are massive, relatively flat slip planes that allow the upper crust to slide laterally for dozens of miles. They often act as a sheer boundary layer separating the brittle, fracturing upper crust from the hot, flowing lower crust.

Metamorphic Core Complexes

Deeply tied to detachment faults, metamorphic core complexes represent areas where the crust has been stretched to its absolute limit. As the upper crust is violently pulled apart and slides away along a detachment fault, the "roof" is essentially removed from the lower crust. This allows deeply buried, highly metamorphosed basement rocks to flow upward in a ductile (plastic) manner and dome up toward the surface. The result is deep, ancient metamorphic rock sitting directly beneath highly faulted, shallow sedimentary rock, separated by a distinct slip plane.

Ridge Isostatic Rebound

Despite the crust being stretched incredibly thin, the mountains in the Basin and Range remain impressively tall. This is due to isostasy (crustal buoyancy).As the crust is pulled apart and the graben blocks drop, massive amounts of weight are removed from the lithosphere. Coupled with hot asthenosphere welling up from below, this "unloading" causes the remaining mountain blocks to buoyantly float upward. This upward push—isostatic rebound—offsets the sinking of the valleys, actively keeping the mountain ridges elevated.


38°N
37°N
36°N
35°N
118°W
117°N
116°N
115°N
114°N
25 0 25 50
KILOMETERS
SIERRA NEVADA
COLORADO PLATEAU
Beatty
Pahrump
Las Vegas
Mesquite
I-15
CM
GM
bc
FM
RSR
EM
PM
BM
MVM
MM
FMM
SVM
ov
pv
fm
nd
gf
rv
cd
gl
sd
ps
lv
lm
sw
1
2
3
4
5
6
7
8
9
Eastern Sierran Thrust sheet
Last Chance Thrust sheet
Marble Canyon Thrust sheets
Below the White Top Backfold
Above the White Top Backfold
Lemoigne Thrust sheet
Wheeler Pass Thrust sheet
Keystone Thrust sheet
Autochthon and parautochthon
Cenozoic strata
Mesozoic intrusive rocks

5.3 (3) Sierra Nevada Glaciations

Sierra Nevada Glaciations

Elena Dworak

Sierra Nevadas

The Sierra Nevadas have a long history of glacier cover since before the Holocene (roughly 11.7 kya), there's been thick masses of ice that formed over hundreds and thousands of years from accumulation, compaction, and recrystallization of snow [5, 1]. These small alpine glaciers may disappear by 2100 [5].

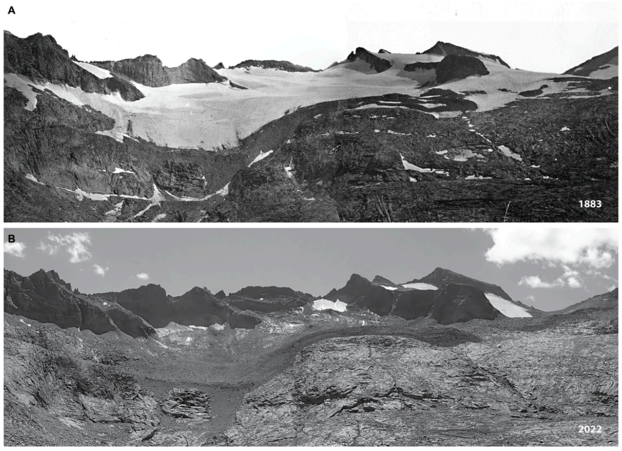
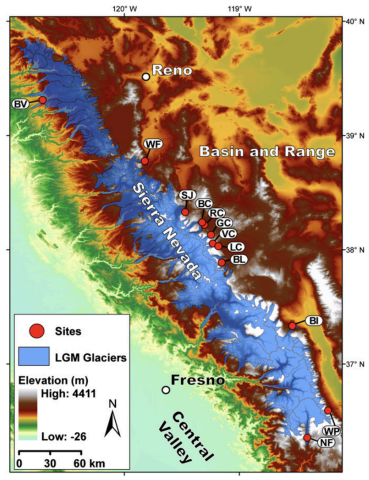


Fig. 2. Repeat photography of East Lyell Glacier.
Yosemite National Park, California. (**A**) East Lyell Glacier, Yosemite National Park, in September 1883. Photo credit: I. Russell, United States Geological Survey. (**B**) East Lyell Glacier in September 2022. Photo credit: G. Stock, National Park Service. Note that East (left) and West (right) Lyell lobes were connected in 1883.

The Sierra Nevadas experienced extensive glaciation in the Northern 500 km of their 600 km range during the Pleistocene glaciation [4], with the most glaciated part between ~ 36°N and ~ 38°N [3]. This translates to the current Stanislaus National Forest on the northern end, and Sequoia National Forest on the southern end. The main Sierra Nevada glaciations throughout the Pleistocene existed within this region, with the main events being from oldest to youngest defined as McGee, Sherwin (ca. 820 ka), Tahoe (170–130 and ca. 70 ka), and Tioga (14–28 ka) [4, 6]. A fourth Pleistocene glacial stage was later defined as Recess Peak (13 ka) [4]. Recent studies have shown there are likely 15 or more major glaciations [3], as research and dating techniques keep increasing this number. The age of these glaciations were measured using geochronological isotope dating with 10Be, 26Al, and 36Cl [4].



Glacial Maximum extent [4]

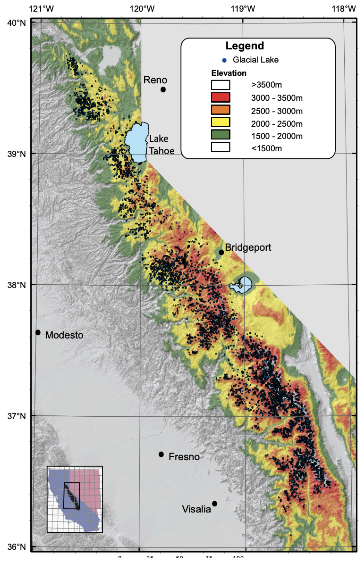
Glacier Formation and Climate

There's historically been latitudinal and longitudinal variations in glacial accumulation in the Sierra Nevadas from precipitation and temperature patterns. These glaciers could grow in the Sierra Nevadas even at relatively low latitudes since there were lower temperatures at elevation and historically reliable precipitation patterns [2]. The North has historically gotten more precipitation on the western slope than in the south, and due to the mountain topography and incoming westerly weather systems there has been heavier precipitation on western slopes especially in high altitude regions. There's also a temperature gradient at the crest range with warmer temperatures to the South [4].

These precipitation and temperature patterns mean that there were lower elevation glaciers and glacial lakes in the North than in the South during the Pleistocene. This is because glaciers form in areas with mass gain from more snow fall in winter than melt in summer, and glaciers recede in areas with more melt than snow gain over time [1]. Also, the glaciers taper off at lower elevations since the head of the glaciers begin at the cirque, where there tends to be more accumulation, and taper off towards the bottom which have greater temperatures with altitude decrease.

Glacial Zones

In the Pleistocene ice ages, ice covered an area of ~20,000 km2, about a third of the range was ice covered with most glaciers above 1500 m in the North and above 2500 m in the South. The lower parts of the glacier system were in major preexisting river canyons where melting dominated, this ice then flowed downhill into river canyons. The boundary between the upper ice growth zone and lower ice loss zone is called the equilibrium line altitude (ELA), which can be nicely estimated by where current glacial lakes lie *(see figure)*. There are currently around 7000 glacial lakes which were exposed after the Tioga glaciation receded, and these lakes a good marker for where there was Pleistocene snow accumulation and are only about 300 m below the ELA [4]. The Sierra Nevadas mostly have valley glaciers, which exist in valleys and mountains and flow down the valley. These glaciations create interesting topography, with valley glaciers forming sharp and angular topography [1]. These glaciations changed the high elevation topography, producing sharp peaks, steep canyons, moraines, and over 7000 lakes [4].



Sierra Nevada Glacial Lakes from retreat of Tioga [4]

Glaciers Today

The glaciers in the Sierra Nevadas are far from their maximum with three orders of magnitude less cover than in the Pleistocene. It was recently projected that under most global warming scenarios the small alpine American West glaciers will disappear by 2100. Palisades and Lyell are some of the longest existing glaciers in the Sierras, and they have experienced a significant size reduction in the past century, and are not predicted to last much longer. The glaciers are sensitive to climate changes on the current scale, and their shrinking widely affects freshwater storage, river runoff, and biodiversity [5].

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5.4 (4) Magmatic History of the White-Inyo Range

The magmatic history of White-Inyo Range

26 WI GE136b
Sophia Ji-In Ree

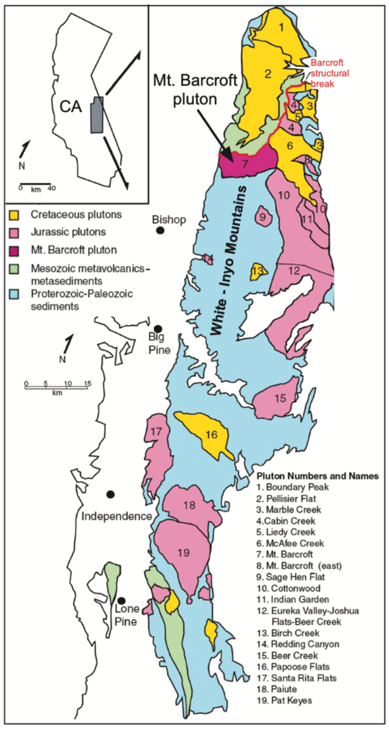


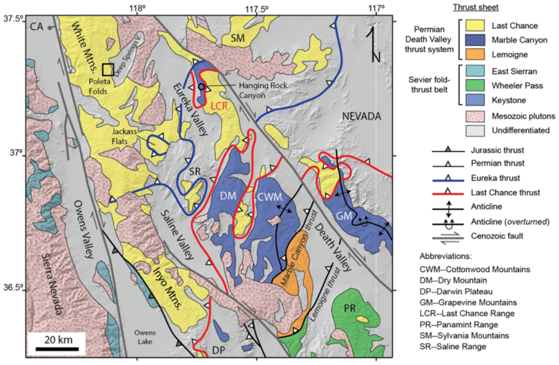
Figure 1. Simplified geological map of the White-Inyo Range showing Mesozoic plutons (Ferre et al., 2012)

CA
N
0 km 40
Mt. Barcroft pluton
Barcroft structural break
🟨 Cretaceous plutons
🟪 Jurassic plutons
🟥 Mt. Barcroft pluton
🟩 Mesozoic metavolcanics-metasediments
🟦 Proterozoic-Paleozoic sediments
Bishop
White - Inyo Mountains
Big Pine
N
0 5 10 15
km
Independence
Lone Pine
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Pluton Numbers and Names
1. Boundary Peak
2. Pellisier Flat
3. Marble Creek
4.Cabin Creek
5. Liedy Creek
6. McAfee Creek
7. Mt. Barcroft
8. Mt. Barcroft (east)
9. Sage Hen Flat
10. Cottonwood
11. Indian Garden
12. Eureka Valley-Joshua Flats-Beer Creek
13. Birch Creek
14. Redding Canyon
15. Beer Creek
16. Papoose Flats
17. Santa Rita Flats
18. Paiute
19. Pat Keyes

Geological Background

The White–Inyo Range is a NS trending mountain system in eastern California comprising the White Mountains and the Inyo Mountains, which are separated by Westgard Pass but form a geologically continuous structural block. The range is part of the western Basin and Range Province, and forms the eastern boundary of Owens Valley (Figure 2). Geologically, the White–Inyo Range lie within a transitional zone between the Mesozoic continental volcanic arc of the western Cordillera (represented by the Sierra Nevada batholith) to the west, and the Phanerozoic North American craton to the east (Morgan and Law, 1998).

Figure 2. Map of White-Inyo and adjacent basin and ranges (Zuza et al., 2025)



118º
117.5º
117º
37.5º
37º
36.5º
CA
White Mtns.
Deep Springs V.
Poleta Folds
SM
Hanging Rock Canyon
Eureka Valley
LCR
NEVADA
N
Jackass Flats
SR
DM
CWM
GM
Owens Valley
Saline Valley
Marble Canyon thrust
Death Valley
Lemoigne thrust
Sierra Nevada
Inyo Mtns.
PR
Owens Lake
DP
20 km
Thrust sheet
Permian Death Valley thrust system
Last Chance
Marble Canyon
Lemoigne
Sevier fold-thrust belt
East Sierran
Wheeler Pass
Keystone
Mesozoic plutons
Undifferentiated
Jurassic thrust
Permian thrust
Eureka thrust
Last Chance thrust
Anticline
Anticline (overturned)
Cenozoic fault
Abbreviations:
CWM--Cottonwood Mountains
DM--Dry Mountain
DP--Darwin Plateau
GM--Grapevine Mountains
LCR--Last Chance Range
PR--Panamint Range
SM--Sylvania Mountains
SR--Saline Range

Timing of plutonism

Most of the White-Inyo Range is covered with deformed Late Proterozoic to Paleozoic strata intruded by several Mesozoic plutons. High precision U-Pb zircon geochronology study of Coleman et al., 2003 revealed that the plutonism can be grouped into two short-lived events that occurred at 180-165 Ma and 102-86Ma separated by a magmatic quiescence of 60 Ma. With the intrusion age of 179 Ma, Beer-Creek pluton is the oldest dated pluton of the White-Inyo range and one of the oldest among the Mesozoic western American Cordilleran arc.

Petrogenesis

Initially, the granitic plutons of White-Inyo Range were interpreted as satellites of the Sierra Nevada Batholith because of similarities in age and composition (Bateman et al., 1963). The well studied Sierra Nevada batholiths are quartz-rich and calc-alkalic (lower in Na_2O and K_2O than alkalic rocks, but high in CaO and Al_2O_3). It is considered the "type" continental margin intrusive complex. However, some parts of the White-Inyo plutons are much more alkalic (high in Na_2O and K_2O), less silicious, and older than the Sierra Nevada Batholith (Sylvester et al., 1978).

Figure 4. Photos of fabrics in the Eureka Valley–Joshua Flat–Beer Creek Pluton. (A) JFM: Joshua Flat Monzonite, BCG: Beer Creek granite (B) Microstructure of the JFM (Morgan et al., 2013)

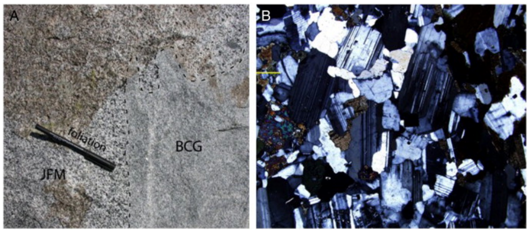
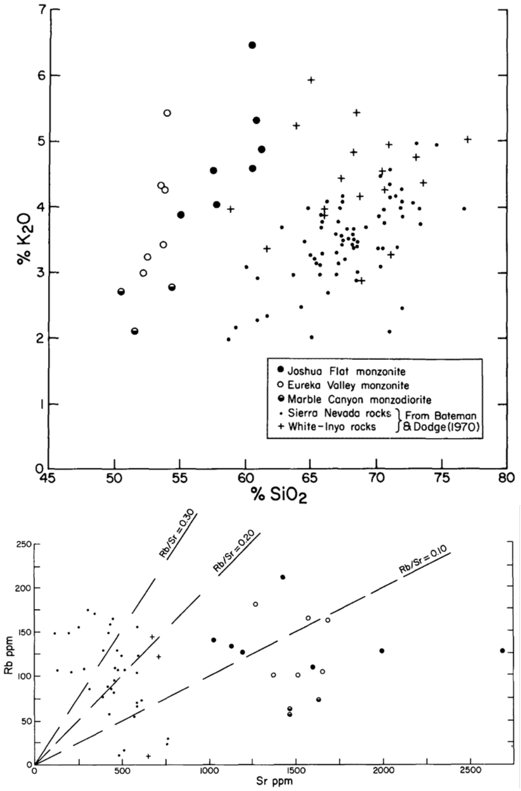


Figure 3. Top: K_2O vs. SiO_2 Bottom: Rb vs. Sr of White-Inyo monzonites compared to Sierra Nevada and other White-Inyo Range rocks (Sylvester et al., 1978)



This portion is represented by the monzonites of the White-Inyo Range. According to Sylvester et al., 1978, these monzonites are characterized by low silica contents (<60 wt.% SiO_2), exceptionally high total alkalis (K_2O + Na_2O >8 wt.%), and very high Sr concentrations (>1000 ppm), along with normative compositions near the silica-saturation boundary.

Field relationships and petrographic textures demonstrate fresh igneous fabrics, sharp intrusive contacts, and compositional homogeneity within plutonic units, arguing against metasomatic alteration or post-intrusive alkali enrichment. Likewise, assimilation of limestone or other sedimentary rocks is inconsistent with the low initial $^{87}Sr/^{86}Sr$ ratios (~0.705–0.706), which indicate minimal crustal contamination. Fractional crystallization from a typical calc-alkaline magma also fails to explain the data, as such processes would generally drive residual melts toward greater silica saturation and lower Sr, rather than producing undersaturated, Sr-enriched compositions.

The high Sr abundances are particularly diagnostic and imply partial melting at pressures where plagioclase is unstable (>40–80 km depth), consistent with generation in the upper mantle. In this context, small degrees of partial melting of a subduction-modified mantle source could yield potassic, Sr-rich magmas capable of producing both quartz-bearing and feldspathoidal monzonites. The White–Inyo monzonites are therefore best interpreted as early, mantle-derived alkalic melts emplaced inland from the main Sierra Nevada arc axis, representing a discrete but temporally overlapping magmatic pulse within the evolving Mesozoic arc system.

References

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Coleman et al., 2003; Timing of plutonism and deformation in the White Mountains of eastern California

Ferré et al., 2012; Vertical zonation of the Barcroft granodiorite, White Mountains, California: Implications for magmatic processes

Morgan and Law, 1998; An Overview of Paleozoic-Mesozoic Structures Developed in the Central White-Inyo Range, Eastern California

Morgan et al., 2013; Forceful emplacement of the Eureka Valley–Joshua Flat–Beer Creek composite pluton into a structural basin in eastern California; internal structure and wall rock deformation

Sylvester et al., 1978; Monzonites of the White-Inyo Range, California, and their relation to the calc-alkalic Sierra Nevada batholith

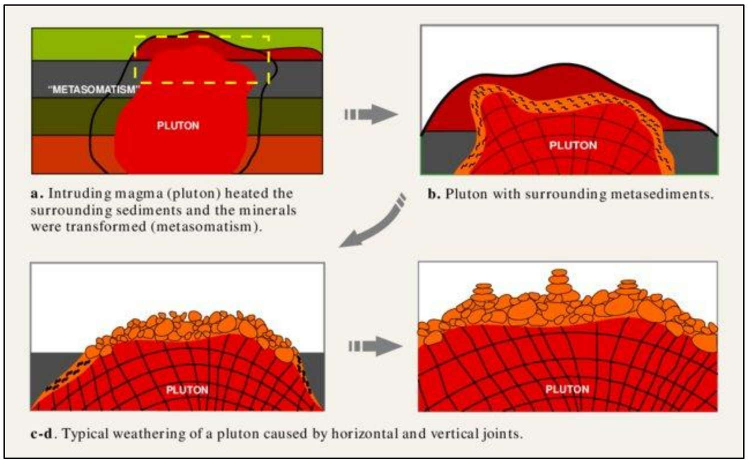
Zuza et al., 2025; The White-Inyo Mountains, CA: An integrated classroom laboratory to learn about plate-boundary processes

5.5 (5) Hunter Mountain Pluton

Hunter Mountain Pluton (Jurassic)
Amanda Bednarick

Around 170 million years ago, an intrusive body of quartz monzonite intruded the Paleozoic sediments that compose most of the Saline/Eureka/Panamint Valley area. The Hunter Mountain Pluton cooked the sediments as it ascended and intruded, creating a contact aureole that hosts metal deposits and an unusual quantity of wollastonite.

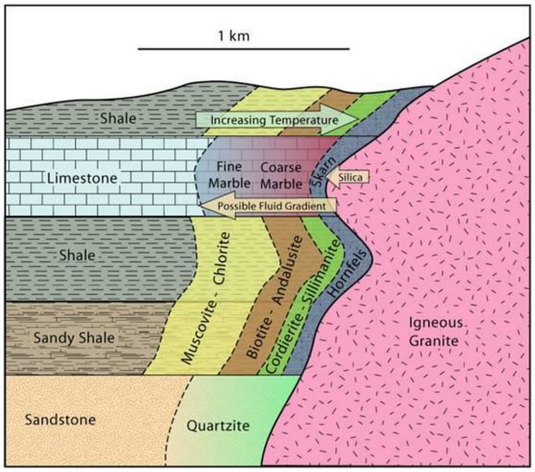
^


"METASOMATISM"
PLUTON
PLUTON
PLUTON
PLUTON

a. Intruding magma (pluton) heated the surrounding sediments and the minerals were transformed (metasomatism).

b. Pluton with surrounding metasediments.

c-d. Typical weathering of a pluton caused by horizontal and vertical joints.


1 km
Shale
Increasing Temperature
Limestone
Fine Marble
Coarse Marble
Skarn
Silica
Possible Fluid Gradient
Shale
Muscovite - Chlorite
Biotite - Andalusite
Cordierite - Sillimanite
Hornfels
Sandy Shale
Igneous Granite
Sandstone
Quartzite

^From Herzog et al., 2008 – this schematic shows the evolution of a pluton from molten magmatic intrusion to cool, crystalline topographic high

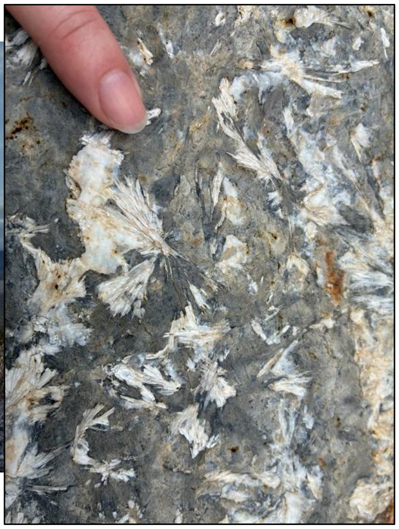
← From the Geological Society of Glasgow – baking different flavors of sedimentary rock will result in different assemblages of metamorphic minerals. The metamorphism is most intense, and thus the most dramatic mineral transformations occur, near the interface with the hot igneous body. The contact is a weak zone, and fluids (magma-derived or otherwise) are driven along here, adding mass and complicating the metamorphic reactions.

Hunter Mountain Pluton is a quartz monzonite (granite) batholith and today it is exposed over more than 70 miles. The Jurassic intrusion is responsible for the existence of one of the world's largest wollastonite deposits in the metasediments within its contact aureole. There are also several mines in the immediate vicinity – the metamorphic fluids associated with the intrusion are responsible for the copper, silver, and gold metals left behind in the strata.

~A dozen igneous bodies intruded Inyo sediments from ~230 to ~80 Ma. The oldest ones (NY Butte, Marble Canyon) are characterized as diorite. Monzonite bodies come next (180-175 Ma – e.g. Joshua Flat, Eureka Valley), followed by dominantly quartz monzonites (including Hunter Mountain, which is the largest). The geochemistry seems to have trended towards more evolved (more felsic) compositions through time.

Casual statements online about the Hunter Mountain Pluton representing the easternmost reach of Sierra Nevada magmatism seem to stem from some ancient literature (1960s). Given the granitic composition, location, and geochronology, it seems reasonable to think they are related, but someone should probably check!

Us walking out of Panamint's Big Four Mine (Pb-Zn-Ag-Au-Cu) this past New Years. The Panamint Dunes (made of Hunter Mountain Pluton material) are in the northwest distance (to the right), so Hunter Mountain is just out of view, to the right of the dunes!



What is this?? Wollastonite? We saw it in a wash in Panamint Valley

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5.6 (6) Mining in the Inyo Mountains

Metal and Mettle in the Inyo Mountains

Korbi Thalhammer

The Inyo Mountains are a ~70 mile long fault block mountain range that separates Owens Valley (to the west) and Saline Valley (to the east). They are primarily composed of deep sea sedimentary layers deposited between the Neoproterozoic and the Paleozoic. In the Mesozoic, these layers were folded by tectonic action, thrust eastward, and intruded by a series of granitic magmas (primarily quartz monzonite) associated with the Sierra Nevada Batholith. The contact metamorphism caused by the intrusion of these plutons into the sedimentary layers created the metal rich veins and skarns that form the basis for extensive mining, especially along the Inyo Mountains' western flank. The primary resource in the Inyos is gold. Silver, lead, zinc, tungsten, and talc have also been mined in the range with varying levels of success.

The richest mine by far was Cerro Gordo, which, during its operation between 1875 and 1933, produced more money (~17 million dollars in silver, lead, and zinc) than all the other mines in Eureka, Saline, and Panamint valleys combined.

Many of the mines in the Beveridge Mining District on the eastern side of the Inyos are rich in gold compared with other deposits in the United States. But they were so inaccessible that early miners couldn't construct rail lines or roads and had to carry their ore out on foot. To this day, mining the eastern side of the Inyos has remained effectively out of reach, though many small-scale operators have made limited profits.

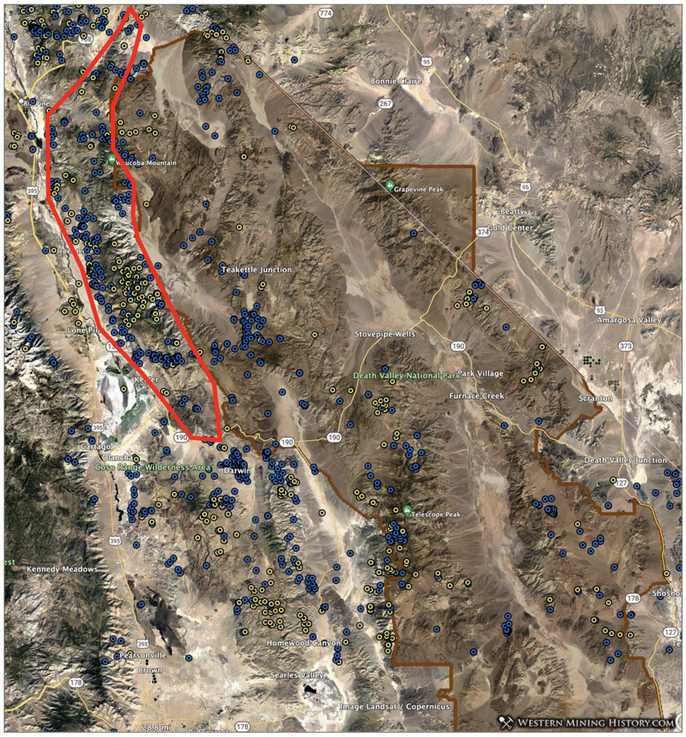
Bonnie Claire
Grapevine Peak
Beatty
Gold Center
Teakettle Junction
Stovepipe Wells
Death Valley National Park
Furnace Creek
Amargosa Valley
Scranton
Death Valley Junction
Telescope Peak
Darwin
Coso Range Wilderness Area
Kennedy Meadows
Homewood Canyon
Searles Valley
Pearsonville
Image Landsat / Copernicus
WESTERN MINING HISTORY.COM

Figure 1: Productive mines in the Death Valley region. Red lines denote the approximate extent of the Inyo Mountains. Saline valley is the beige/white patch tucked into the east side of the crescent formed by the Inyos. Yellow points are gold mines, blue points are non-gold mines. Map modified from the original found at westernmining-history.com.

Death Valley's most precious modern resource? Scott Swaney.

This retired oil worker spends weeks every year wrestling monster loads up sheer ridges so he can rappel thousands of meters down remote canyons. He is a pioneer in the Death Valley Canyoneering community and continues to document first descents in the region.

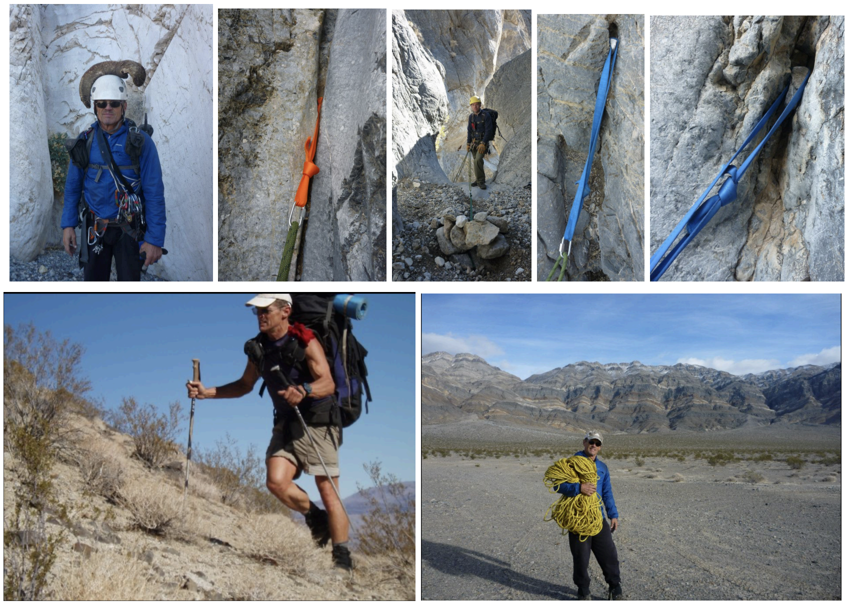

Figure 2: Clockwise from top left: Scott protecting the canyon walls (see tributes below); various anchors to which Scott and partners entrust their lives while rappelling DV canyons, including a knot chock, a rock pile (cairn), and two examples of rock chocks; Scott at the base of the Last Chance Range holding 600 feet of static line he carried on his first descents in the canyons surrounding Eureka Valley; Scott heading uphill as part of an 2500m ascent from Saline Valley with 22kg of overnight gear, rappelling equipment, and drinking water for a two day ascent/descent of Pat Keyes Canyon. The previous party (a BLM outfit) took 4 days.

Some tributes from Rope Wiki, where Scott has documented his 300+ descents in the Death Valley region, including over 200 first descents.

- Scott Swaney carries two ascenders with him at all times: his left hand and his right hand.
- When Scott Swaney constructs a 6:1 haul system, he rigs it backwards so he can raise the person faster.
- Scott Swaney wears a helmet so that he doesn't damage canyon walls.

References: 1) https://westernmininghistory.com/mine-county/california/inyo/ 2) https://www.outsideonline.com/gallery/68-year-old-canyoneer-legend-descending-death-valley/ 3) Digonnet, M. (2023). *Hiking western death valley National Park: Panamint, saline, and eureka valley* (2nd ed.). Michel Digonnet.

5.7 (7) Trilobite and Archaeocyathid Fossil Morphologies in the Saline Valley and Harkless Formations

Ge 136: 2026

Trilobite and archeocyathid fossil morphologies in the Saline Valley and Harkless Formations

Magdalene MacLean
Division of Geological and Planetary Sciences, California Institute of Technology

(Dated: February 19, 2026)

I. GEOLOGIC STRUCTURE AND HISTORY OF THE SALINE VALLEY AND HARKLESS FORMATIONS

The Saline Valley and Harkless Formations are sedimentary rock strata in what is now eastern California and western Nevada deposited in the early Cambrian period, with the former overlying the latter[1].

The Harkless Formation is dominated by siltstones and fine- to medium-grained quartzite, representing a low-energy shallow-water environment. Carbonates are rare in this formation, contrasting both the underlying carbonates in the Poleta Formation and more limestone in the Saline Valley Formation. The siltstones of this formation are known for a greenish-gray coloration rich in muscovite and chlorite. Where there is limestone, it is found in the lower, older regions of the formation, suggesting coastal regression over this period. Near the bottom of the formation there is a thin bed of purple-tinted pisolitic limestone. The contact layer between the Harkless Formation and the Saline Valley Formation is a layer of gray to brown limestone[1].

The Saline Valley Formation has much more variation both vertically and horizontally and is made up of quartzites, sandstones, limestones, and siltstones. This is loosely divided into a lower quartzite-dominated member capped with a nearly 10 meter layer of quartz-bearing limestone and an upper shale- and limestone-dominated member. This likely represents a marine transgression over this period wherein the seas got deeper over time, reducing the deposition of large sediment grains[1].

II. TRILOBITE FOSSIL AND TRACE FOSSIL MORPHOLOGIES

The initial dating of these two formations was based on the trilobite fossils present therein; as lower Cambrian formations, trilobites dominate their fossil inventory.

Though rare in most Cambrian fossil beds, particularly in the early Cambrian, the Saline Valley Formation has an abundance of trilobites in the genus *Ogygopsis*[1]. This genus is well-studied as one of the sites where it is abundant is the Burgess Shale. These trilobites are recognized by their very long and rounded pygidium (rearmost body segment), uniform body width, relative lack of spines, and prominent eye ridges[2]. Particularly well-preserved specimens may even preserve antennae[3]. The Inyo mountains are a type site for some species in this genus, particularly *O. batis* and *O. klotzi*[1][4]. While these trilobites are most abundant in parts of the Saline Valley Formation outcropping in Nevada, they are abundant throughout the Saline Valley outcrops and can even be found in the upper hundred meters of the Harkless Formation[4].

The uppermost strata of the Saline Valley formation and its contact with overlying strata is host to fossils of genus *Olenellus* (formerly *Paedumias*), trilobites with a nearly perfectly semicircular cephalon (head) and two prominent slits or furrows inward from the eye ridges. These fossils also show a pronounced narrowing of their thorax segments as they go away from the head, giving an overall teardrop shape. The most abundant species of this genus found at this site is *O. nevadensis*[1]. These are one of the defining fossil groups used to date these sediments.

Throughout both sites, trilobite fossils of genus *Bristolia* (formerly *Olenellus*) are found with characteristic angular cephalon shapes and trailing thorasic spines[5]. These trilobites are small and spiny compared to the generally smoother other varieties abundant in these beds. These are another of the defining fossil groups used to date these sediments[1].

Alongside proper trilobite fossils, there are also trace fossils believed to have come from trilobite activity. These are mostly in the form of *Cruziana* type ichnofossils, parallel scratched trails from trilobite walking[6]. These are preserved in quartzite in the Harkless Formation and in siltstones in the Saline Valley Formation[1].

III. ARCHEOCYATHID FOSSIL MORPHOLOGIES

The limestone layers of the Harkless Formation are among the best sites in North America for archeocyathid sponge fossils[7]. Several of those limestone layers with incredibly dense assemblages of archeocyathid fossils along with other fossilized fauna, indicating those sites as reefs[1][8]. However, archeocyathids are also found in beds with much lower activity. This indicates a variety of lifestyles and niches filled by these early Cambrian animals.

Among the diversity of archeocyathids preserved in this site are conical reef-building members of the genera *Diplocyathellus*, with complex wall morphology, and *Metaldetes*, with longer bodies[9]. Also present is the less-common genus *Retilamina*, mainly represented by *R. debrenneae sensu*, which is noted for having fossilized algal biofilm materials on its underside. This suggests

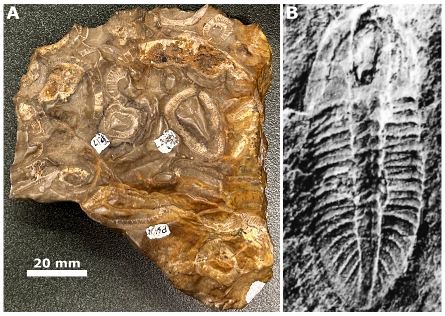

FIG. 1. A: Archeocyathid-fossil-bearing rock sample from the Harkless Formation. The morphology of these archeocyathids is consistent with the genus *Diplocyathellus*[9]. Sample courtesy of Joe Kirschvink. B: *Ogygopsis* trilobite fossil with the characteristic uniform-width body and long, round pygidium[2].

the close relationship these reef-builders had with other species and similar ecological associations to those between algae and reef-building organisms today[8].

An especially unique taxon found at this site is a species of archeocyathid that lived as an epibiont, attaching to other archeocyathids rather than the seafloor. This species, *Robertiolynthus handfieldi*[8], also helps to illustrate the structural and ecological complexity of these early reefs. Structural complexity also is present in the form of branched members of the genus *Arrythmocricus*[9].

Also preserved in the Harkless Formation is a negative carbon isotope excursion just above the last of the archeocyathid fossils[8]. This matches a pattern of a similar excursion at the point of archeocyathid extinction globally and marks the end of the age of archeocyathid reefs.

IV. OTHER KNOWN FOSSIL MORPHOLOGIES

Both the Harkless Formation and the Saline Valley Formation have rich inventories of other fossils beyond the aforementioned groups.

One category of paleontologically important fossils are trace fossils preserving burrowing behavior, specifically the vertical burrowing of *Skolithos*-type ichnofossils[1]. These represent one of the defining innovations leading into the early Cambrian, that being the evolution of vertical burrowing behaviors. These coexist with a variety of horizontally-oriented traces akin to those from the upper precambrian. Both varieties are found throughout the quartzite layers of the Harkless formation.

Abundant throughout the Harkless Dormation but especially in the siltstone and limestone layers are the 6-10 mm conical fossils of genus *Salterella*, characteristic small shelly fauna that have recently been theorized to be relatives of cnidarians[10][11].

There are other less-abundant fossil groups represented in these layers, notably brachiopods[10][8] (especially in the Harkless Formation), other less-characterized small shelly fauna[10], hexactinellid (glass) sponges[8], rare echinoderms[8], algal fossils in the uppermost members of these layers[1], and even possible spiral-shelled *Pelagiella* mollusks in the archeocyathid reefs[8]. These were dynamic ecosystems and their diversity and occurence is still a topic of research as these formations offer one of the best windows into early Cambrian life on the shores of Laurentia.

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— Saline Valley Warm Springs: Night 1 —

5.8 (8) Geochemistry of Saline Valley Warm Springs

In Hot Water – Geochemistry of Saline Valley Warm Springs

Sarah Davis – Ge136B – 2026

Where is the Water?

Water is relatively scarce in the Great Basin of Death Valley. The region is so dry that even places like China Lake, Searles Lake, Lake Panamint, and Lake Manly hold no considerable water for most of the year – even at such low elevations. For instance, though China lake is dubbed a “lake”, at some 650 meters above sea level[1], the community of China Lake was built directly on the lakebed. Even Lake Manly, located in Badwater Basin – the lowest point in North America (-86 meters), is an ephemeral lake that only exists after periods of significant rainfall. Considering the arid climate of Saline Valley, it is puzzling then that warm springs exist in the area year-round.

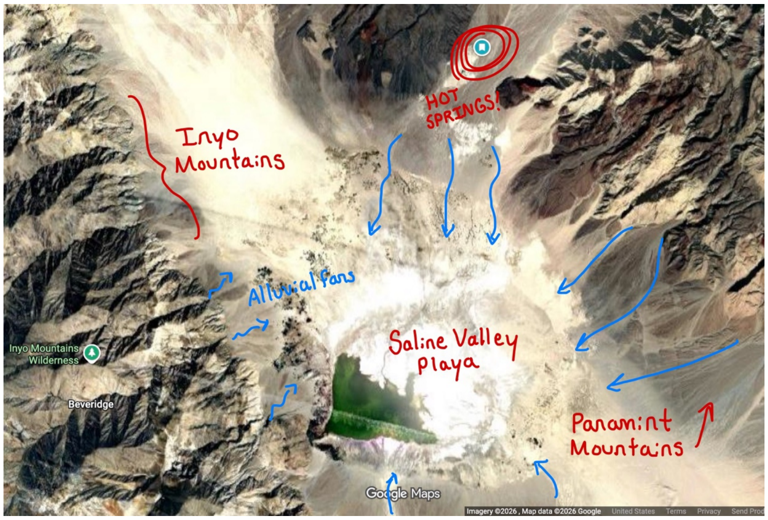
HOT SPRINGS!
Inyo Mountains
Alluvial Fans
Saline Valley Playa
Panamint Mountains
Inyo Mountains Wilderness
Beveridge
Google Maps
Imagery ©2026 , Map data ©2026 Google United States Terms Privacy Send Prod

Figure 1. Saline Valley playa. Blue arrows show possible water pathways down from the Inyo and Panamint mountains.

Saline Valley is situated between the Inyo mountain range and the Panamint range, just west of Death Valley. Since the basin is surrounded by mountains, the water that flows from the peaks via snowmelt is collected at the playa (Figure 1) and exits via evaporation or dispersal down through alluvium. The water that remains becomes saturated with salts (i.e., becomes a brine). At its center, the brine is ~27-29% salt solution[2]. The warm springs themselves are located to the north of the playa.

The springs are a result of the geothermal gradient – not volcanism. The most recent igneous activity was during the Pliocene. Because Saline Valley is a graben in-between two normal faults, local fracturing results in deep convective heating (down to ~1000 meters) of the groundwater reservoir and brings hot water to the surface as hydrothermal springs[3,4].

What’s in the Water?

Around the hot springs, travertine is deposited via the release of CO_2 gas from the hot water. Considering colder waters can store more CO_2 gas, warm waters experience precipitation of carbonates as a result of lower CO_2 solubility. Hot waters, then precipitate minerals like calcite and aragonite at high rates:

$$
\begin{gathered}
CO_2 + H_2O \rightleftharpoons H_2CO_3 \\
H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \\
HCO_3^- \rightleftharpoons CO_3^{2-} + 2H^+ \\
Ca^{2+} + CO_3^{2-} \rightleftharpoons CaCO_3
\end{gathered}
$$

These reactions aren't the only drivers of pH in hydrothermal systems. Carbonic acid is a weak acid (pH ~5) while other acids like sulfuric acid (H_2SO_4) with a pH ~3 can be produced in such environments due to the reaction of hydrogen sulfide with the atmosphere:

$$
\begin{gathered}
2H_2S + 3O_2 \rightleftharpoons 2H_2O + 2SO_2 \\
SO_2 + 2H_2O \rightleftharpoons H_2SO_4 + H_2
\end{gathered}
$$

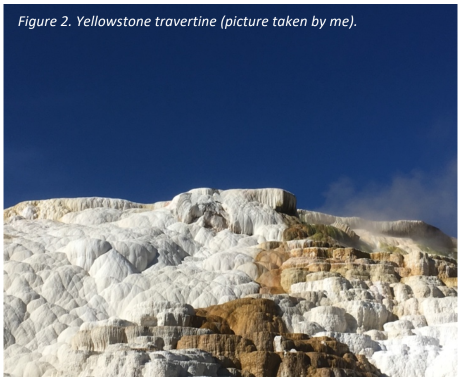

Figure 2. Yellowstone travertine (picture taken by me).

The production of sulfuric acid is largely through volcanism-driven hydrothermal systems when magma releases sulfur species. In these cases, the springs are acidic. However, in Saline Valley, deep circulation and convection results in prolonged interactions between hot water and silicate minerals, effectively buffering pH and producing alkaline waters (pH between 7.0 and 8.4)[2]. The springs' temperatures range from 94.4˚F to 116.8˚F (34.6˚C to 47.1˚C). Measurements of dissolved ions amongst various hot springs in the area show total dissolved solids (TDS) ranging from 323ppm to over 1000ppm. The dominant species (ions) in saline valley hot spring water were sodium, bicarbonate, and sulfate with maximums of 240ppm, 417ppm, and 450ppm, respectively. Other major ions detected were calcium, magnesium, potassium, and chlorine[2]. This amalgamation of TDS stems from the major mineral assemblages of the playa: gypsum, halite, and glauberite ($Na_2Ca(SO_4)_2$).

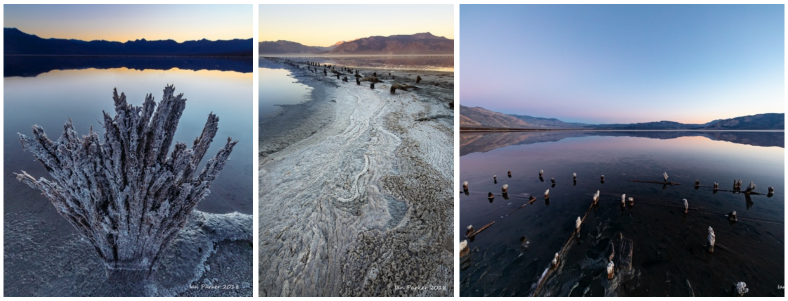

Figure 3. Salt formations at the Saline Valley playa. Images via Ian Parker, 2018[5].

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5.9 (9) Saline Extremophiles

Extremophiles and Saline Lakes
Jordan Chastain, Ge136b Winter 2026

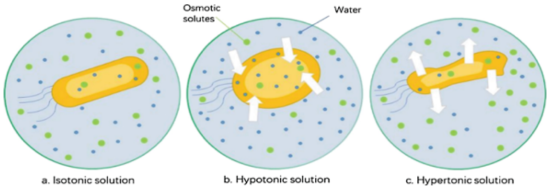
Organisms that are adapted to live in extreme environments are commonly called extremophiles. Some types include halophiles (salt-loving), thermophiles (heat-loving), and acidophiles (acid-loving). The extreme environments in which extremophiles live are often difficult to survive in multiple ways. For example, saline lakes commonly form in low latitude and/or high altitude regions, concentrating salts due to extreme evaporation by heat or aridity. Organisms living in these environments encounter and deal with many issues:

Salt[1,2]

High salt contents can affect protein structures and water content in cells.

Common Solutions:

- Chaperone proteins to help with protein folding
- Ion transport proteins to modulate intracellular concentrations to match outside
- Accumulate “osmolytes” to mimic high salt

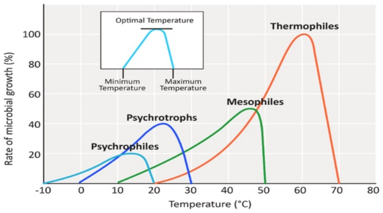

Osmotic solutes
Water
a. Isotonic solution
b. Hypotonic solution
c. Hypertonic solution

Temperature[3,4]

Cellular temperatures outside normal can affect viscosity, membrane permeability, and protein folding

Common Solutions:

- Chaperone proteins to help with protein folding
- Modify protein sequences to fold in extreme temperatures
- Modify membrane lipid structures

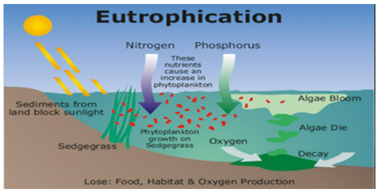


Low Oxygen[5,6]

Increased salinity and temperature reduce O_2 solubility in water, limiting energy availability (as can agricultural input of salts and nutrients)

Common Solutions:

- Increase oxygen intake/storage (breathing, hemoglobin)
- Limit energy consuming processes
- Use anaerobic metabolism


Eutrophication
Nitrogen
Phosphorus
These nutrients cause an increase in phytoplankton
Algae Bloom
Sediments from land block sunlight
Algae Die
Phytoplankton growth on Sedgegrass
Oxygen
Sedgegrass
Decay
Lose: Food, Habitat & Oxygen Production

UV Light[7,8]

Ultraviolet light can damage DNA, causing harmful mutations in gene sequences and production of reactive oxygen species

Common Solution:

- Accumulate protective pigments

Class of organisms	*Extremes*	*Organism*	*Growth conditions*
Thermophile	High temperature (>45°C)	*Methanopyrus kandleri* strain 116	122°C (20–40 MPa)
Psychrophile	Low temperature (<15°C)	*Planococcus halocryophilus* Or1	-15°C (18% NaCl)
Alkaliphile	High pH (pH >9)	*Serpentinomonas* sp. B1	pH 9.5–12.5
Acidophile	Low pH (pH <5)	*Picrophilus oshimae* and *Picrophilus torridus*	pH 0–2.2
Halophile	High salinity (>1% NaCl, <0.994 a_w)	*Desulfovermiculus* sp. and *Desulfobacula* sp.	Nearly saturated $MgCl_2$, $a_w \sim 0.4$
Radiation resistant	High radiation	*Circinaria gyrosa*	47 kGy
Oligotrophs	Low energy/nutrient	*Acetobacterium woodii*	$\Delta G_P = 30.2$ kJ/mol $\Delta G_{ion} = 9.1$ kJ/mol

Current “limits of life” discovered so far, displayed by the most extreme conditions in which we have observed life survive (modified from the 2024 Astrobiology Primer, because this impacts our understanding of habitability!)[9]

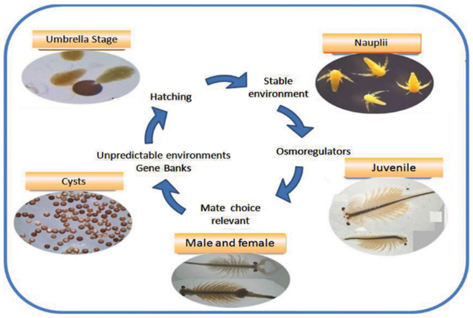
Case Study: Salty Macroscopic Friends in Lake Windsor, Great Inagua

A beautiful hypersaline lake on Great Inagua Island in the Bahamas, used by Morton Salt for NaCl production, and a home for many salt-loving and salt-tolerant organisms

Brine Shrimp[10]:

These tiny invertebrates dominate invertebrate populations in saline lakes around the world due to their numerous adaptions:

- Salt excretion: brine shrimp have specialized ion transporters that force out salt from their cells across steep concentration gradients
- Offspring: Females can either produce offspring as cysts or free-swimming based on how variable the environment is
- Efficient respiration: As salinity can decrease dissolved oxygen, brine shrimp can modulate hemoglobin synthesis
- Osmoregulation: Hundreds of osmoregulation molecules to help protein folding and membrane structure



Life cycle of brine shrimp, showing essential salt responses at each stage[10]

Mangroves[11,12,13]:

Red, white, and black mangroves have all found a home on Great Inagua, both on the island's coastlines and in the isolated Lake Windsor. These lake mangroves are thought to remain from times of higher sea levels, since isolated from the coast. In general, mangroves survive salty water through:

- Salt exclusion: Mangroves (especially red) can filter away salt and uptake freshwater through their roots
- Salt excretion: Mangroves excrete salt from leaf glands, sometimes enough to form visible crystals
- Cell Strength: Strong cell walls to resist osmotic shock

Beautiful red mangrove behind this random fisherman at Lake Windsor[14]

Red Mangrove
Black Mangrove
Button Mangrove
White Mangrove

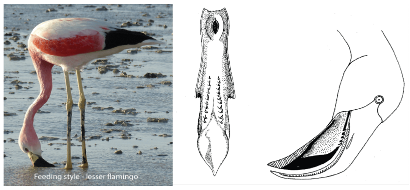
Flamingos[15,16]:

These beautiful pink waterbirds are found in numerous saline lakes around the world, including Lake Windsor. They feed on the brine shrimp and algae of the lake, taking advantage of the lack of predators.

Flamingos have numerous adaptions to survive and thrive in their saline habitats. These include:

- Filter-feeding structures in beaks to filter out large particles and only eat small ones
- Salt glands that secrete the salt they ingest
- Tough skin on legs that allow them to stand in salty hot water for hours
- Inhabit regions with many lakes, following algal blooms for food

Walter Nixon, Inagua Senior Park Warden, protects flamingos[15]



Filter feeding structure in flamingo beaks[16]

Adult flamingos in Lake Windsor[15]

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5.10 (10) Cenozoic Tectonics of Saline Valley

Cenozoic Tectonics of Saline Valley

Victor Vescu - Ge136b - Winter 2026

Introduction

Saline Valley is a narrow basin in the North of the Mojave Desert, located within the broader Basin and Range Province (Figure 1). What makes it interesting is that it lies in a region where two deformation styles overlap: (1) Basin and Range Extension (i.e., pulling the crust apart, creating normal faults and mountain-front basins) and (2) Walker Lane shear zone transtension (Figure 2) (i.e., extension plus right-lateral strike slip that helps accommodate the Pacific-North America plates' motion). In the Saline Valley area, these processes interact through the Hunter Mountain Fault Zone, which connects deformation between nearby basins and transfers slip through the region.

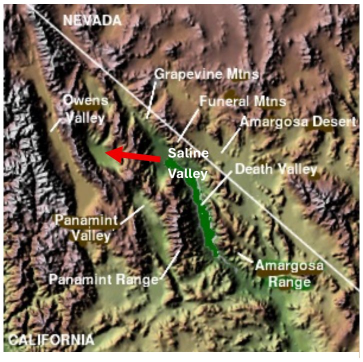

Figure 1: Regional map of Saline Valley and Panamint Valley.

Regional Setting

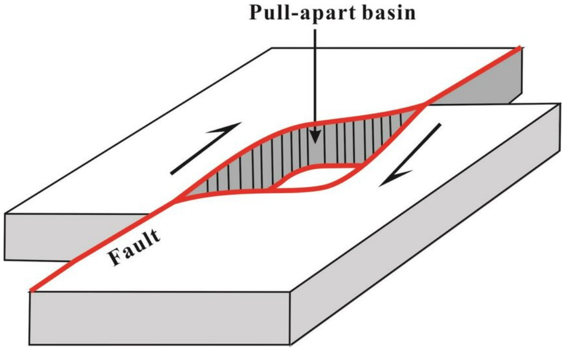

Figure 2: Pull-apart basic block diagram

Saline Valley is a piece of a larger Cenozoic story in the Death Valley region. Instead of a single continuous episode of extension, the region preserves evidence for multiple tectonic stages separated by shorter intervals of rapid change. Cenozoic basin-fill deposits (~40-2 Ma) are preserved not only in valleys but also stranded within mountain uplifts, implying repeated basin formation, deformation, and uplift over time. Regional unconformities act as markers of short-lived "tectonic reorganizations," separating longer-lived tectonic stages (Fridrich & Thompson, 2011). In Saline Valley, a modern basin-and-range landscape is the latest expression of a longer, multi-stage Cenozoic tectonic evolution, with faults being reactivated and reorganized over time.

Key Geologic Structures

Although there are many mapped faults, these structural elements are especially important for explaining Saline Valley's Cenozoic tectonics:

1. Hunter Mountain fault zone (HMFZ): dominantly right-lateral strike-slip, acting as a transfer structure between basins. Panamint Valley and Saline Valley are paired pull-apart (Figure 3) basins on opposite sides of this right-slip system (Burchfiel et al., 1987).
2. Range-front normal faults along the margins of Saline Valley: these accommodate vertical motion (uplift of ranges, subsidence of the basin) and help generate the classic basin-and-range topography. Both strike-slip and normal components show up along different parts of the system.
3. Faults within the valley (internal normal faults and splays): additional normal fault strands inside Saline Valley, part of a system that helps transfer strike-slip motion onward through the region (Oswald and Wesnousky, 2002).

How did the basin develop during the late Cenozoic?

Much of the “modern” Saline Valley–Panamint Valley pull-apart system is late Cenozoic, with significant basin development in the late Pliocene to recent. 8–10 km of late Cenozoic net slip can be established on the Hunter Mountain fault zone, indicating major cumulative right-lateral displacement. Saline Valley appears to have formed during the last ~3 million years, but possibly by a different near-surface extensional style - more like closely spaced, rotated normal faults rather than one dominant low-angle detachment. The two neighboring basins may be mechanically linked by the strike-slip transfer fault, but the details of how extension is expressed at shallow crustal levels can vary from one basin to the next.

Quaternary to present

By the Quaternary (the last ~2.6 million years) and especially the Holocene (last ~11,700 years), faulting is clearly active and leaves strong geomorphic fingerprints (offset channels, fault scarps, and disrupted young alluvial surfaces). Holocene deposits are offset along the fault zone: in Grapevine Canyon, Oswald, J.A., & Wesnousky (2002) report ~50–60 m of right-lateral channel offset and interpret incision to be on the order of ~15 ka, yielding an implied slip rate of about 3.3–4.0 mm/yr there. Not all faults in the valley accommodate motion at the same rate. Some northerly-trending normal faults within Saline Valley yield very low slip-rate estimates (hundredths of millimeters per year), indicating that deformation can be unevenly partitioned across the fault network.

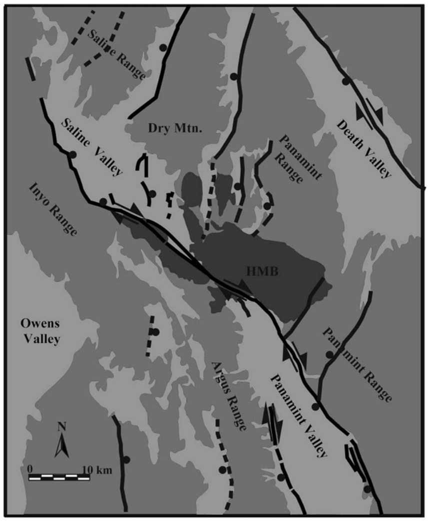

Figure 3: Sketch map of the Hunter Mountain Batholith showing the 10 km of right-lateral offset along the Hunter Mountain fault zone.

Conclusion

Saline valley was formed by: (1) Regional Cenozoic transtension (extension + right-lateral shear) affected the Death Valley region in multiple stages, with episodes of reorganization recorded by unconformities and changes in basin development, (2) strike-slip motion on the Hunter Mountain fault zone, which helped link and transfer deformation between neighboring basins (Panamint and Saline), contributing to pull-apart–style basin geometry at the regional scale, and (3) normal faulting along range fronts and within the basin, which accommodated the extensional component, building topography (uplifted ranges) and subsidence (basin fill), while the strike-slip system continued to move and reorganize the network through time.

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5.11 (11) Saline Valley

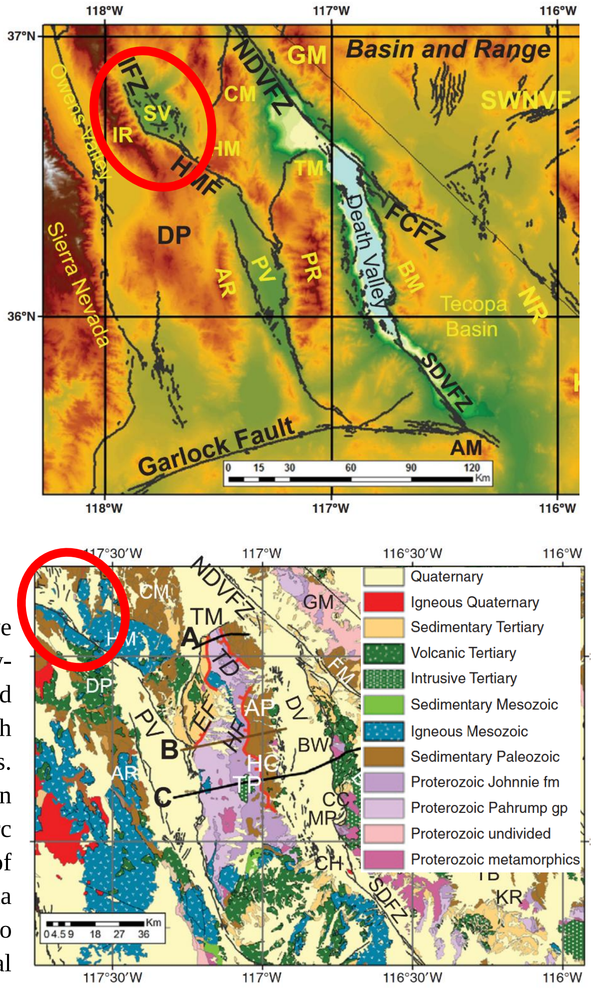
Geologic History of the Saline Valley

Abby Keebler

Saline Valley is one of many basins in the Basin and Range Province, bounded by Inyo Mountains to the west and Last Chance Range to the east. It is part of the same regional deformation system as Death Valley.

The Big Picture

1. Deposition of marine rocks during the Paleozoic; deformation in the Mesozoic
2. Basin and Range extension begins in the Cenozoic (Miocene); Saline Valley is one of many
3. Saline Valley basin fills with sediments primarily delivered by runoff from precipitation
    a. Basin subsidence plus uplifted sediment sources (surrounding mountains) = thick basin fill
    b. Playas and evaporites form since is a closed basin
    c. Volcanism & hot springs due to all the faulting


118°W
117°W
116°W
37°N
36°N
Basin and Range
GM
NDVFZ
CM
SWNVF
IFZ
SV
IR
HMF
HM
TM
Owens Valley
Death Valley
FCFZ
DP
AR
PV
PR
BM
Tecopa Basin
NR
Sierra Nevada
SDVFZ
Garlock Fault
AM
0 15 30 60 90 120 Km
117°30′W
116°30′W
CM
NDVFZ
GM
TM
A
HM
FM
TD
DP
AP
DV
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HF
B
BW
HC
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C
CC
MP
CH
SDFZ
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TB
0 4.5 9 18 27 36 Km
Quaternary
Igneous Quaternary
Sedimentary Tertiary
Volcanic Tertiary
Intrusive Tertiary
Sedimentary Mesozoic
Igneous Mesozoic
Sedimentary Paleozoic
Proterozoic Johnnie fm
Proterozoic Pahrump gp
Proterozoic undivided
Proterozoic metamorphics

Figure 1: Topographic and geologic maps of the Death Valley Area; Saline Valley circled in red. *Norton (2011)*

Phase One: Paleozoic Stratigraphy

During the Paleozoic, the region lay along a passive continental margin, where thick sequences of shallow-marine carbonates and shales accumulated on a broad continental shelf. These marine strata now form much of the basement exposed in the surrounding ranges. Beginning in the Mesozoic, subduction of the Farallon Plate beneath North America initiated widespread arc magmatism and crustal shortening. Emplacement of granitic plutons associated with the Sierra Nevada Batholith records prolonged magmatic activity linked to this convergent margin. Concurrently, compressional tectonics during the Sevier and later Laramide orogenies thickened and deformed the crust, producing regional folding, thrusting, and uplift that overprinted earlier marine sequences.

Phase Two: Cenozoic Basin and Range Extension

Starting around 20 million years ago, the tectonic regime of eastern California shifted from Mesozoic compression to widespread crustal extension associated with development of the Basin and Range Province. Beginning in the Miocene, regional extension led to crustal thinning and the formation of normal-fault-bounded basins and uplifted mountain ranges. The area spread apart along detachment surfaces and then at 3 Ma, the East California Shear

Zone developed pull-apart basins, forming the present-day topographic depressions of the Death Valley region. The Saline Valley is one such basin bounded by normal faults along the Inyo Mountains and the Last Chance Range. The Saline Valley is one of the deepest basins in the area, with Cenozoic fill thought to exceed 3 km in depth (Figure 2).

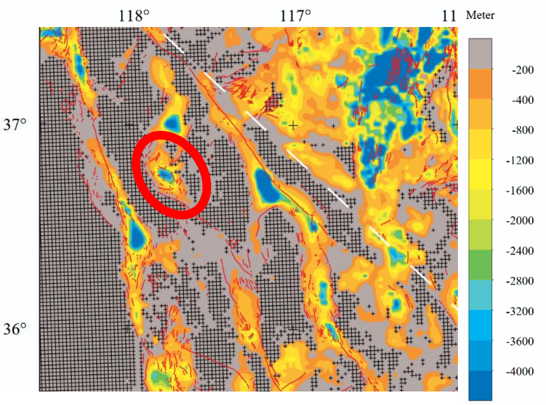


Figure 2: Thickness of Cenozoic deposits of Death Valley extended terrain, as calculated by gravity inversion. Grey = less than 200m of Cenozoic deposits; other colors as indicated in legend. *Blakely et al. (1999)*

Phase Three: Quaternary Processes

At the basin margins, Quaternary sedimentation has been dominated by alluvial fan development and episodic debris flows from canyons in the Inyo Mountains and Last Chance Range. Steep relief and infrequent but intense precipitation events generate high-energy sediment transport, delivering coarse gravels to the basin floor. Over time, alluvial fan deposits have prograded basinward, interfingering with finer-grained lacustrine and playa deposits.

During Pleistocene pluvial intervals, cooler and wetter conditions promoted the development of a closed-basin lake (often referred to as pluvial Lake Saline), with expanded surface area and shoreline features preserved along basin margins. As climate shifted toward more arid conditions, lake levels fell and exposed fine-grained lacustrine sediments. Evaporation without runoff to restore the lake resulted in the concentration and precipitation of evaporite minerals in the basin center. Today, similar processes continue on a smaller scale: groundwater discharge into the internally drained basin sustains saline playas where evaporation drives ongoing evaporite formation.

Quaternary tectonic activity has also facilitated hydrothermal circulation and localized volcanism. Fault zones provide pathways for deep groundwater flow, feeding the well-known Saline Valley warm springs along the eastern margin of the basin. Thank you, tectonics, for giving us such a nice place to chill once we make it over the rough roads to our field site!

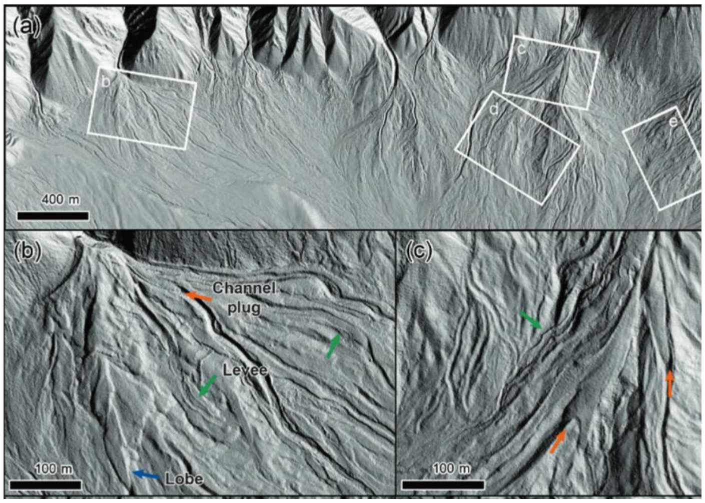


Figure 3: Lidar hillshade data showing complex fan morphologies due to overlapping events. *De Haas et al. (2024)*

References: Blakely, R. J., Jachens, R. C., Calzia, J. P., & Langenheim, V. E. (1999). Cenozoic basins of the Death Valley extended terrane as reflected in regional-scale gravity anomalies. | de Haas, T., Lau, C. A., & Ventra, D. (2024). Debris-flow watersheds and fans: Morphology, sedimentology and dynamics. *Advances in debris-flow science and practice*, 9-73. | Norton, I. (2011). Two-stage formation of Death Valley. *Geosphere*, *7*(1), 171-182. | Reheis, M. C., Adams, K. D., Oviatt, C. G., & Bacon, S. N. (2014). Pluvial lakes in the Great Basin of the western United States—a view from the outcrop. *Quaternary Science Reviews*, *97*, 33-57.

5.12 (12) Flora of Saline Valley

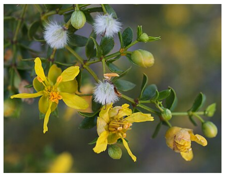
Flora of Saline Valley Field Guide

GE136B Winter 2026

Arden Shao

Creosote bush

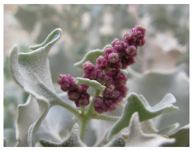
Larrea tridentata



A medicinal herb with three-toothed leaves, yellow flowers, and fuzzy seeds towards the base of the flower that are covered in white hairs. Creosote grows at an angle to minimize the amount of direct sunlight received in the harsh desert climate. It can grow 1-3 m tall and is often associated with the "smell of rain," or petrichor. It is capable of reproduction via seeds but also cloning! Rings of creosote have been estimated to live for thousands of years.

Desert holly

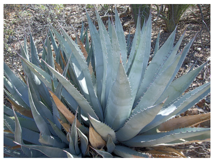
Atriplex hymenelytra



A silvery-grey-colored shrub with twisting leaves. It is an adaptive, drought-tolerant saltbush that typically blooms from January to April and can grow 1-2 m tall. Its fruits occur in clusters and are pressed together at the extremity, very reminiscent of the common holly we know from Christmas.

Agave

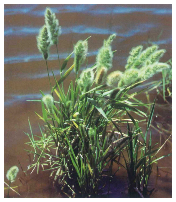
Agave sp.



Agave is invasive in many arid regions, including Saline Valley. At the end of its long life, it tends to grow a long, towering, flowering stalk that can reach several meters tall.

Annual rabbitsfoot grass

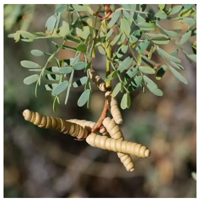
Polypogon monspeliensis



Considered an invasive weed. Has stems that are long and slender, up to ~17 cm long. Flowers from April through October. The flowering tip takes on a soft egg-like shape that tapers off at the end. Tends to grow near moist sites.

Screwbean mesquite

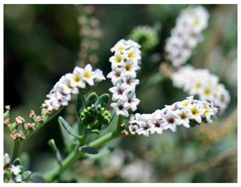
Prosopis pubescens



This is a very common tree to find in Saline Valley. Screwbean mesquite has light brown bark, long prickly spines that grow in pairs along branch nodes, and compound leaves composed of many, many small leaflets attached to a common stalk, called a rachis. Its most distinct feature is its seed pods that resemble a screw. Some theorize this morphology is due to an adaptation against seed-eating creatures, such as the bean weevil.

Salt heliotrope

Heliotropium curassavicum

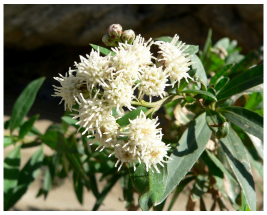


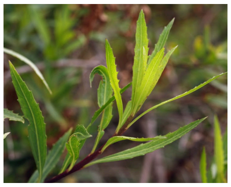
A flowering perennial that thrives near water sources that have alkaline or saline soils.

The flowers have a bell-like curve, with five petals and a center that turns from yellow to purple as the flower matures. Typically ~0.5 meters tall. It flowers in spring and has thick, fleshy leaves and stems, like that of a succulent.

Mule Fat

Baccharis salicifolia





A flowering shrub that can grow over 3 m tall. It derives its name from the fact mules would get fat eating the leaves or perhaps because the leaves would cause them to become bloated. It has compound clusters of feathery flowers that are often white in color in Saline Valley but can also be pink or reddish. Not all mule fat will be flowering, so when it is not in bloom, keep an eye out for oblong leaves with serrated edges.

Willow

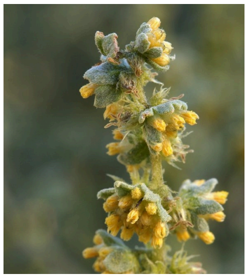
Salix spp.

While not extremely abundant in the extremely sunny climes of Saline Valley, a specific species called the Arroyo Willow (a small, fast-growing, and deciduous variant) can be found in Saline Valley. Willow trees also have leaves with serrated edges, but unlike Mule Fat, it is more glossy. Willows generally grow well in areas with full sun and proper water drainage. They can be an important haven/resource for wildlife (birds, insects, amphibians, and mammals).

Burrobush

Ambrosia dumosa

Like many of the other shrubs on this list, the Burrobush is a common sight of the creosote-bush scrub region (a desert vegetation type that constitutes a good portion of Saline Valley). It has been studied that the Creosote bush actually releases chemicals through its roots which inhibit the growth of Burrobush in the nearby space, thereby creating regions of "dead zones" around the Creosote bush. This relationship between the two species is known as an *allelopathic interaction*.



Burrobush itself is a form of ragweed. Younger stems are covered in soft hairs. It has a fast growth rate and spherical fruits. Its pollen can cause serious allergic reactions.

References

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(4) "Polypogon monspeliensis." *Calscape*, California Native Plant Society.
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s.gov

Salt Tolerant Microbes of Saline Valley

Ge 136B Field Report

Stella Baldwin
Division of Geological and Planetary Sciences, California Institute of Technology
February 20th, 2026

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1. Definitions of Salt Tolerance in Microbial Communities

Salt tolerance and salt dependence are one of the many ways to phenotypically classify microorganisms. "Halotolerance" generally describes microbes that can survive under high salt conditions (> ~2.5 M NaCl) [1]. "Halophilic" generally describes extremophile microbes that require high salt concentrations to survive [1]. Slight halophiles grow best with 0.5-2.5 M NaCl [1]. Moderate halophiles grow best with 1.5-4.0 M NaCl [1]. Extreme halophiles grow best with 2.5-5.2 M NaCl [1]. However, it is important to note that the exact definition of each halophilic category varies, as studies report slightly different numbers [2]. Regardless, halotolerant and halophilic microorganisms survive and thrive under higher-than-average salt conditions.

Halotolerant and halophilic microbes are found in all three domains of life. Bacterial phyla such as *Cyanobacteria*, *Firmicutes*, *Actinobacteria*, and *Proteobacteria* contain halophiles [1].. The archaeal class *Halobacteria* also contains several halophiles [1]. Finally, there are some eukaryotic fungi and *Plantae* that are halophilic microbes [3].

Halophilic microbes have two methods for osmotic regulation. The first is the "salt-in" method. This involves accumulating high [KCl] inside the cytoplasm, excluding sodium ions [1]. However, proteomes must be specialized and acidic for this to occur, so many that use this mechanism are salt-dependent [1]. The second is the "salt-out" method. Microbes accumulate organic solutes (i.e., glycine betaine) that balance osmotic pressure without disrupting their cytoplasmic salt concentrations [1]. The "salt-out" mechanism tolerates a wide salinity range with minimal cell proteome changes, so many microbes utilize this method.

2. Environmental Conditions and Parameters of Saline Valley

Saline Valley contains a large, dry lake near the center, surface brines ~0.5 meters deep, and a salt marsh [4]. These surface brines are fed by groundwaters [4]. Surface brines can evaporate to salinities greater than 30%, which can form halite crusts with brine inclusions [4]. There are several places halophilic microbes can live in Saline Valley, including surface brines, mudflats, lakes, hot springs, and halite crystals (*Figure 1*) [4]. To explore paleoenvironments, one can obtain borehole cores with interbedded salt and mud layers, which can possess fluid inclusions containing microbes trapped for up to 150 thousand years [4].

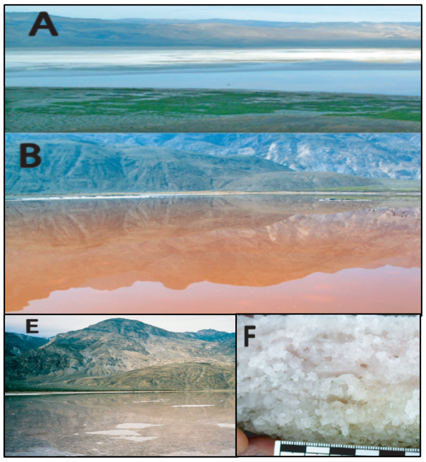


FIG 1. Saline Valley: Locations where microbes can live. Modified from Lowenstein et al. (2011). **A)** Saline pan and mudflats. **B)** Saline lake. **E)** Surface brine. **F)** Halite crust.

3. Example Halophilic Microbe of Saline Valley – *Dunaliella*

Dunaliella (*Figure 2*) is a unicellular photosynthetic green alga (under the eukaryotic kingdom *Plantae*) commonly found in saline conditions [5]. It uses the “salt-out” method to tolerate salinities as high as 30% [5], accumulating organic solutes like glycerol and β-carotene (a carotenoid) [6]. *Dunaliella* can grow rapidly in extreme conditions due to their fast adaptability to stress [6].

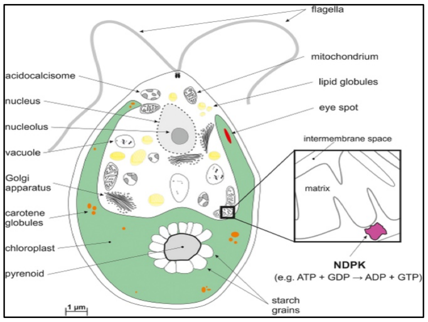
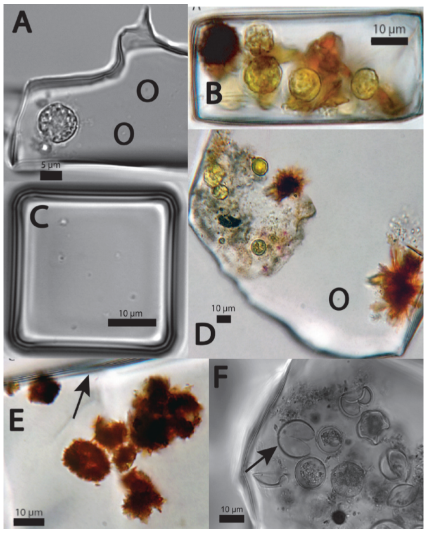

flagella
mitochondrion
lipid globules
eye spot
intermembrane space
matrix
NDPK
(e.g. ATP + GDP → ADP + GTP)
starch grains
acidocalcisome
nucleus
nucleolus
vacuole
Golgi apparatus
carotene globules
chloroplast
pyrenoid
1 µm

FIG 2. Cartoon schematic of *Dunaliella*. Taken from Woyda-Ploszczyca and Rybak (2021).

Dunaliella can also be found in Saline Valley. Lowenstein et al. (2011) took borehole cores from both Death Valley and Saline Valley to analyze microbial communities within fluid inclusions (*Figure 3*) [4]. When they did, they discovered Dunaliella within Pleistocene deposits, trapped in fluid inclusions up to 150 thousand years old.


A
O
O
5 µm
B
10 µm
C
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D
10 µm
O
E
10 µm
F
10 µm

FIG 3. *Dunaliella* in fluid inclusions from Saline Valley halite crystals. Taken from Lowenstein et al. (2011).

4. Conclusion

Microbes thrive under a variety of extremophile conditions, including high salinity. Saline Valley provides the perfect environment for several halotolerant and halophilic microbes (i.e., *Dunaliella*).

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5.14 (14) Desert Plant Healing, Rituals, and Material Culture

Desert Plant Healing, Rituals, & Material Culture

Isaac N. Aguilar

Introduction: Tending the Desert Wilderness

The Southern Deserts of California are often mischaracterized as overlooked wilderness. Though, California Indians did not distinguish between managed land and wild "preserves". A hands-off management paradigm perpetuated by colonial hegemony has promoted feral landscapes that have not been taken care of by humans for a long time and are becoming inhospitable to life. When intimate interaction with the plants and animals cease, the continuity of generational knowledge is broken and the land becomes "wilderness".

The Indigenous peoples of the Saline Valley region developed sophisticated relationships with the desert flora since time immemorial (Table 1). Their languages are distinct although within the Uto-Aztecan language family. Social organization followed a gradient of resource availability: "family" groups in scarcer areas and "band" groups where abundance permitted larger aggregations. Leadership remained fundamentally egalitarian; shamans (*puagants*) wielded influence through their ability to manipulate *puha* (spiritual power), but coercive political authority was absent. During summer months, family groups migrated to communal sites in cooler elevations like Hunter Mtn. where productive harvesting of piñon nuts, seeds, roots, and berries supported 50-100 people. The summer harvest was a time to reunite with relatives, celebrate marriages, and transmit ceremonial knowledge. With the onset of cool weather, groups descended to valley floor villages where mesquite groves and springs provide winter resources to live in the deserts (**Fig. 1**).

Group	Autonym	Language
Timbisha Shoshone	Tümpisa	C. Numic (Shoshoni)
Owens Valley Paiute	Nüümü	W. Numic (Mono)
W. Shoshone	Newe	C. Numic (Shoshoni)
N. Paiute	Numu (Paviotso)	W. Numic (N. Paiute)
Kawaiisu	Nuooah	S. Numic
Tubatulabal	Pāhān-āpĭl	Tubatulabalic
Koso/Panamint	Koso	C. Numic (Shoshoni)

Table 1. Indigenous people in the Saline Valley.

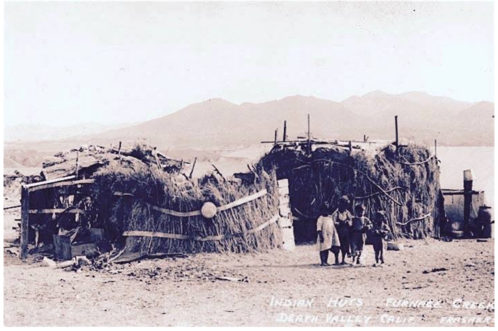

Fig 1. Traditional shelters constructed from desert plants and materials. (1930)

Plant Foods

The annual piñon pine (*Pinus monophylla*) harvest concentrated dispersed family groups onto ceremonial harvesting grounds, transforming subsistence labor into communal celebration. Piñon is notable for its high carbohydrate content (54%), unsaturated fatty acids, and presence of all twenty amino acids[1]. The green cones are roasted to release seeds, remove resin, and enhance digestibility. Seeds are winnowed in basket trays bearing elegant designs, the rhythmic tossing motion separatse nutmeat from chaff while scattering some seeds to ensure future harvests.

Mesquite (*Prosopis glandulosa*) dominated the valley floor villages that sustained winter populations. The pods contain 25-30% sugar and significant protein, ground into a sweet flour called *péchita* that could be stored indefinitely or mixed with water to form cakes or beverages. The wood fueled cooking fires, and the thorny branches formed corrals and windbreaks.

Seeds formed the dietary foundation across the region, their diversity providing security against the failure of any single crop. Chia (*Salvia columbariae*} seeds were parched and ground into a flour rich in omega-3 fatty acids. Dock (*Rumex* spp.) seeds were ground into porridge. Indian rice grass (*Achnatherum hymenoides*) seeds were parched, winnowed, and ground into flour or added whole to stews. Saltbush (*Atriplex confertifolia*) provided both edible seeds and leaves that served as a salt substitute, abundant on the alkaline valley floors.

To prepare seeds for consumption, they were lightly roasted in a tightly woven winnowing basket with live coals. The heat enhanced flavor while loosening husks and chaff, which separated from the heavier seeds as the weaver tossed them skillfully in the air.

Seeds could then be eaten whole, pounded into flour with a milling stone, or added to stews and gruels. Some seeds inevitably flew too far or bounced from gathering baskets, but this loss was not lamented as some seeds needed to fall on the ground to produce the next year's crop. This incidental scattering might not sustain plant populations over time; for this reason, Indigenous peoples deliberately saved seeds and broadcast them in appropriate habitats.

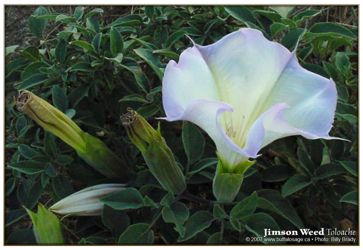

Fig. 2. The *Datura* (Toloache) or Jimson Weed is a sacred ancestral plant in Native cosmovisions.

Plants for Medicine, Healing, and Sacred Ritual

The bark of arroyo willow (*Salix lasiolepis*) contains salicin, a white crystalline glucoside that the body converts to salicylic acid – the original ingredient in aspirin[2]. Willow bark tea treated headaches, fever, and inflammatory conditions. Branches gathered in fall and dried through the cold winter air yielded bark with optimal salicin content.

The distinctive fragrance of big sagebrush (*Artemesia tridentata*) is produced by volatile oils (camphor, thujone, 1,8-cineole). Leaves were burned and the smoke inhaled for respiratory congestion, sinus infections, and colds. Leaf poultices treated wounds with antimicrobial terpenes preventing infection. A tea from the leaves soothed stomachaches and was used as a general tonic. Sagebrush bark is used to wrap ceremonial objects and smudging for ritual cleansing.

California's native tobaccos (*Nicotiana* spp.) were widely used by tribes in rituals as offerings and medicinally to heal cuts and as an emetic. The earth was loosened with digging sticks, and leaves were pruned to enhance their size. North-facing slopes were selected to "pile brush over the ground and then burn it, which would leave the ground with a loose layer of wood ashes. Over this they would sow the seed and protect the crop by putting around it a brush fence. From year to year they would select from the best stalks," and seed for the next year[3]. Tobacco was smoked in ceremonies, offered to spirits, and applied medicinally to cuts. The emetic plant induced vomiting and purified participants before rituals. Toloache (*Datura* spp.) contains tropane alkaloids that induced hallucinations, altered perception, and communion with the spirit world; it is used in puberty rites, vision quests, and shamanic practice (**Fig. 2**).

Baskets and Material Culture

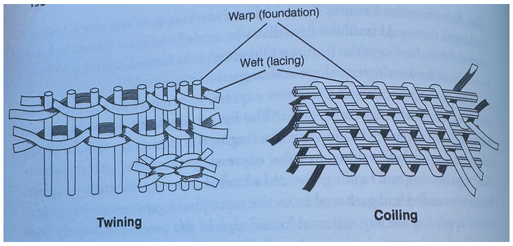

Fig 3. The two basic basketry weaving techniques.

A well-equipped kitchen contained basketry pots, pans, and serving dishes: some windowed and parched seeds, others held stone-boiled soup and strained manzanita cider. Baskets have symbolic meaning in Native cultures and often gifted to strengthen kinship ties. Native peoples took advantage of basketry plants' natural ability to sprout after disturbances. Burning or mechanical pruning stimulated epicormic growth for long straight shoots required for warp and weft (**Fig 3**). To rely on natural lightning fires for this purpose would be uncertain, thus California Indians had to manage the vegetation to obtain sufficient regular supplies of materials. The approximately 25 weavers in a prehistoric village of 100 persons might harvest on the order of 250,000 shoots in a single season[4].

Joshua tree (*Yucca brevifolia*) provided the strongest plant fibers available in the Southern Deserts. Leaves were soaked, pounded, and the fibers extracted for cordage, nets, sandals, and snares. The roots produced a soap rich in saponins, used for washing hair and hides. Milkweed (*Asclepias* spp.) and Indian hemp dogbane (*Apocynum cannabinum*) yielded finer fibers twisted into string for nets and bags. Cattail (*Typha domingensis*) leaves were woven into mats for shelters, bedding, and the outer covering of tule boats.

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5.15 (15) Tracing the History of Water in the Great Basin with O and H Isotopes

Tracing the History of Water in the Great Basin with O, H Isotopes

Sophia Westerkamp

Introduction

The Great Basin is located in the southwestern United States, spanning the majority of Nevada and Utah, as well as parts of California, Idaho, Oregon, Wyoming and Mexico [1]. The geology of the Great Basin is renowned for its basin and range topography, and contains both the lowest and highest points in the contiguous United States [1]. The Great Basin contains the largest area of sequential watersheds with no outlet to the Ocean in North America [1]. As such, the Great Basin presents a great opportunity to understand North American hydrological cycles.

All precipitation into the Great Basin will eventually evaporate, sink into groundwater, or flow into (primarily saline) lakes [1]. The majority of precipitation comes into the Great Basin as snow and meltwater, and a minority as rain [1].

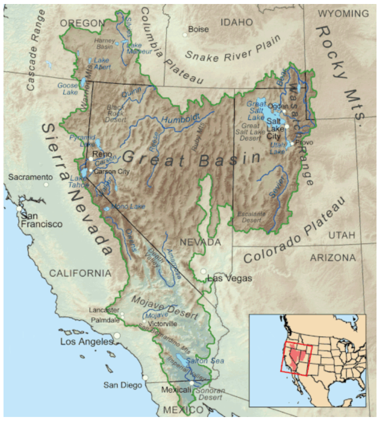
OREGON
IDAHO
WYOMING
Cascade Range
Columbia Plateau
Snake River Plain
Rocky Mts.
Boise
Harney Basin
Lake Malheur
Lake Albert
Silvies
Goose Lake
Warner Mts
Quinn
Black Rock Desert
Humboldt
Great Salt Lake
Ogden
Salt Lake City
Great Salt Lake Desert
Wasatch Range
Bear
Provo
Utah Lake
Sierra Nevada
Pyramid Lake
Reno
Carson
Carson City
Reese
Ruby Mts
Great Basin
Sacramento
Lake Tahoe
Walker
Mono Lake
Sevier
Escalante Desert
San Francisco
Owens
Death Valley
Amargosa
NEVADA
Colorado Plateau
UTAH
ARIZONA
CALIFORNIA
Las Vegas
Mojave Desert
Mojave
Lancaster
Palmdale
Victorville
San Bernardino Mts
Los Angeles
Salton Sea
Imperial Valley
San Diego
Mexicali
Sonoran Desert
MEXICO

Figure 1: Relief map of the Great Basin. Figure from [1].

Isotope Measurements and the Meteoric Water Line

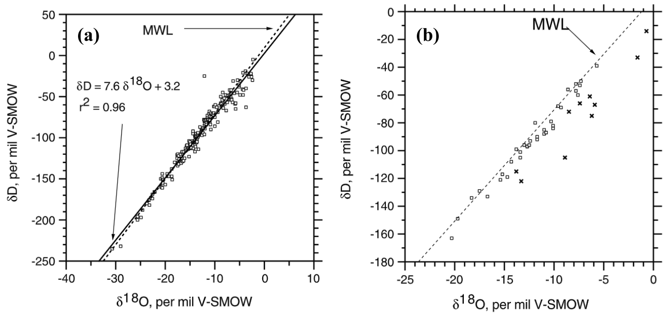

Figure 2: Plots of δD vs δ^{18}O for samples collected at (a) Cedar City, Utah and (b) Winnemucca, Nevada. The dashed line represents the MLW. The majority of data from both sites plots at or near the MLW. Data below the MLW likely underwent evaporation before being collected. Figure from [2].

Isotopes are powerful tracers for geochemical events and mechanisms. In particular, O and H isotopes have long been used as tracers for the Earth's hydrological cycle [3]. In 2002, Irving Friedman and co-authors published a paper titled "Stable isotope composition of waters in the Great Basin, United States 1. Air-mass trajectories" [2]. In this paper, Friedman et al. use hydrogen and oxygen isotopes (specifically δD and δ^{18}O) to trace the trajectories of air masses carrying precipitation into the Great Basin [2]. To do so, they collected precipitation samples from two sites (Cedar City, Utah and Winnemucca, Nevada) across multiple years, and measured the δD and δ^{18}O of the precipitated water samples [2]. They found that the majority of the data for both sites falls near, or at the meteoric water line (MLW), as seen in Figure 2 [2].

The MLW describes the relationship between δD and δ^{18}O for water samples collected worldwide, and tends to trend with latitude [3]. If data falls on the MLW, it implies that precipitation / rainfall was the primary factor influencing isotopic fractionation [3].

How to Fractionate Precipitation: Rayleigh Distillation and Beyond

The concept of "Rayleigh distillation" was first proposed by Lord Rayleigh in 1902 [4]. This model explains how a mixture of two miscible liquids is distilled, assuming that the two liquids have different vapor pressures, are well-mixed, the liquid is in equilibrium with the vapor, and the liquid is constantly being removed [4]. Over time, the vapor will become enriched in the substance with the higher vapor pressure [4]. Because H_2O has a higher vapor pressure than HDO, Rayleigh distillation is relevant to meteorological systems, and can be used to explain why precipitation is highly depleted in heavy D and ^{18}O isotopes.

Other factors that can fractionate meteoritic waters include the isotopic composition of the vapor source, the temperature of evaporation, humidity, the isotopic composition of the air, the history of prior condensation, the temperature of condensation, the size of condensed water, and the amount of evaporation droplets undergo as they fall. As such, precipitation from different sources that follow different trajectories can grow to have wildly different δD and δ^{18}O values.

Where did all the Water Come From?

Based on their varying isotopic compositions, Friedman et al. (2002) grouped their precipitated samples into four major categories [2]. They combined this data with air-mass trajectories to determine the likely source and path of the Great Basin rainfall [2]. As seen in Figure 3, the primary source regions were:

(A) The Gulf of Alaska and north Pacific (‘Arctic’ moisture source).
(B) The central Pacific, passing over the Sierra Nevada (‘Maritime Polar’ moisture source).
(C) The tropical Pacific, passing North of the Sierra Nevada (‘Maritime Tropical’ moisture source).
(D) Originated over land (‘Continental Polar’ / ‘Continental Tropical’ moisture source).
(E) Northwest of the Gulf of Mexico (highly D enriched from warm surface waters) [2].

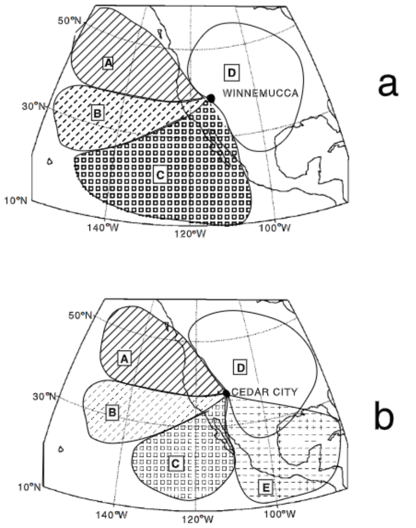

Figure 3: Map of the primary trajectory groupings for air masses causing precipitation at (a) Winnemucca, Nevada and (b) Cedar City, Utah. Figure from [2].

Trajectory C tends to be more enriched in D and ^{18}O than trajectories A and B (Figure 4) [2]. This can be related to the source water for each of these groups - while both A and B come from the northern Pacific, C comes from much further south. This is reflected in the general trend for MLW - water sources closer to the poles tend to be much more depleted in heavy isotopes. Trajectory D falls significantly off the MLW, implying significant non-Rayleigh fractionation.

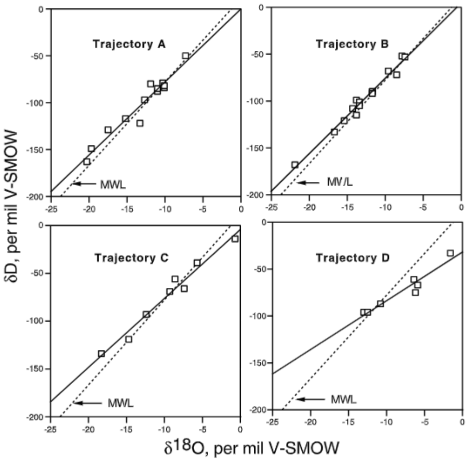

Figure 4: Plots of δD vs δ^{18}O for the four major trajectory types (A, B, C and D) for the precipitation samples collected at Cedar City, Utah. The MLW is the dotted lines. Figure from [2].

The Great Basin clearly sources precipitation from a hugely variable set of trajectories [2]. Though the average flow pattern in the Western United States moves from West to East, the majority of precipitative air masses for the Great Basin flow from southwest to northeast [2]. This is consistent with southwestern monsoonal flow patterns interacting with cold fronts in the North [2].

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5.16 (16) History and Stories from Saline Valley Warm Springs

Amélie Sharples

History and stories from Saline Valley Warm Springs - deaths, floods etc.

The Saline Valley Warm Springs are an extremely remote part of Death Valley National Park. It consists of three springs – the Lower Warm Springs at 110ºF (featuring the Cool Pool, Sunrise Pool, and Crystal Pool), the Upper Warm Spring with a lower temperature of 104ºF, and Palm Spring, reaching up to 112ºF [1]. Palm Spring contains two soaking pools, with the Wizard Pool being about 10ºF hotter than the Volcano Pool, contrary to its name. It takes 50 miles of intense off-roading and torn tires to make it to the springs, and thus they have remained relatively uninhabited for many decades. Despite the remote location, and in fact due to this remoteness, the springs were settled by hippies over 60 years ago. They were later annexed by the Death Valley National Park in 1994, much to the dismay of the locals, who did not want park regulations enforced on their community.

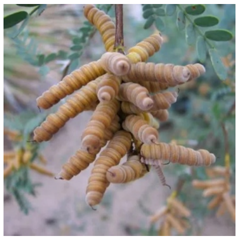
The Warm Springs community has since remained a place for people looking to escape from society or reconnect with nature. While information on this remote site is fairly scarce, I discovered a variety of chronicles written by a user called Tganner, who I later found out is a man called Tom Ganner, on the Time & Space Nature Adventures website. Tom is an old-timer springs inhabitant who remained involved in the tales of Saline Valley for some 37 years. He was encouraged time and again to write a book of his valley adventures from back in the day, and in 2018 he settled on writing a compilation of chronicles under the title "A collection of recollections of days gone by" [2]. He writes of everything from the Bermuda Grass Triangle to a geochemical analysis of the springs (which we will be hearing about from our very own Sarah!) to the Art of Firewood in the valley. For the purposes of this assignment, I will be focusing on the springs specifically, but I recommend giving some of his other chronicles a read because they are quite entertaining:)

The story of the Bermuda Grass Triangle is quite similar to a true crime novel. During the winter break of 1985, a number of campers came to the springs for the holidays. As January of 1986 came around, the holiday campers cleared the area. All except one – a car remained with two camper's belongings scattered, as if the campers had only left for a day hike and intended on returning. This couple were never seen again.

Search and rescue teams spent weeks looking for the missing couple. While typical search and rescue cases would close after a few days, this one lasted on and off for years to come due to the family wealth of the couple and their role as neighbors of the then-POTUS Ronald Reagan. Could this be a plot to get at the POTUS? Was it a brutal murder? Speculation and rumors spread throughout the years. A popular rumor revolved around an infrequent visitor of the springs, called "Wolfman," murdering the couple in cold blood. Wolfman would spend several months at a time in the Saline Valley and other remote desert locations, squatting in various cabins available and avoiding human interaction. The cabin that he inhabited around the time of the couple's disappearance became known as the "Murder Cabin."

In November 1988, several years after their disappearance, a skull was discovered in the valley by a hiker in the area. It was brought to the attention of Tom Ganner, who at this point was the acting "camp host" of the springs (following Chili Bob, who followed Lucky Rich; I'm a big fan of the names in this area). Tom went to check out the region of the first skull discovery for more bones, and low and behold, a second skull was discovered. After continued searching of the area, a man named Sergeant Lewis pointed out the unusual size of a few rocks in a wash where flash floods were known to traverse the terrain. These rocks were too large to have been carried by the system's hydraulics, and their size indicated that they had been placed there purposefully. Indeed, it was revealed that the rocks were placed over the rest of the couple's remains as a sort of shallow burial. The bones were found and catalogued, however the true story of what sealed their fate remains up for speculation.

This was not the first story of missing persons in the Saline Valley Springs. Just the year prior to the missing couple, a camper called Caveman Mike ran around screaming that the devil was trying to get him. He went missing the following day, and days of search and rescue failed to uncover his whereabouts. He was never found, and he had no real connection to the "real" world for questioning. The case was never solved, although he was potentially spotted in another country a few months later.



Outside of unsolved murders and disappearances, there are a number of eccentric characters who frequented the springs and started local traditions. The locals used to ferment honey beans since it was a common enough plant in the area, and a frequent soaker ("soaker" is the term used for those in the local springs region, so when we go there, we will also be joining this umbrella term) by the name of Mammoth Bob claimed these had medicinal and curative powers. Another tradition in the springs was to switch the role of mistletoe with the screwbean plant, pictured to the left. I assume this means locals sometimes kiss under the screwbean plant? However, according to the Los Angeles times, the springs contain "a colorful colony of old hippies, naturists, desert rats and foreign tourists," and "despite the nudity, there's no hanky-panky or sex orgies that go on" [3]. So perhaps the screwbean plant is simply symbolic. There are too many other stories to dive into here, but I'll work on collecting a few more for the trip!

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5.17 (17) History of the Timbisha Shoshone

Jarek Kwiecinski
Ge136b (Saline Valley)

History of the Timbisha Shoshone

Death Valley National Monument was established in 1933 by an executive order from President Herbert Hoover. In its founding document, the monument was described as an uninhabited wilderness fit for preservation in its wild state. However, this characterization was inaccurate, erasing the original inhabitants of this land who saw it as anything but "dead."

To the Timbisha Shoshone, Death Valley and the surrounding area is known as Tüpippüh, or homeland. Tüpippüh is seen as a place full of life and imbued with spiritual meaning. To quote Timbisha elder Pauline Esteves,

"In our religion we don't practice within four walls. Our religion is written in all these mountains and in the valleys, in the waters, in the wildlife: everything that belongs to the Creator. So, we're in church every day."

The tribe's wholistic land management practices reflect this worldview. The Timbisha moved seasonally between semi-permanent villages, wintering on the valley floor near mesquite groves and migrating each summer to mountain elevations where they harvested piñon nuts and hunted bighorn sheep, deer, and jackrabbit. In the valleys, mesquite bushes were pruned at the base to facilitate seed harvesting, a practice which also prevented sand from being trapped by the mesquite trees. Seeds were letter "scarified," increasing water infiltration through mesquite seed coats and promoting germination. Seeds not planted were harvested in late spring and stored to be eaten during the following winter. In this way, mesquite was used as a vital native crop plant, providing both shade and food.

In the mountains, the Timbisha also pruned the lower branches of pinon trees, making it easier to pick up pinecones full of nuts off the ground. To further increase the harvest, the trees were whipped with poles that broke terminal buds, promoting branching and increasing the number of sites where a pinecone could develop. Fire was also a vital management tool, used to promote the growth of wild tobacco, various medicinal plants, and to limit the encroachment of unwanted vegetation onto scarce water sources. Clearly, like much of the American west, the ecosystems of Tüpippüh did not exist as wilderness prior to Euroamerican settlement but were instead carefully managed to support thousands of people who possessed a deep understanding of the area's ecology.

Tüpippüh includes lands beyond what we call Death Valley. A band of the tribe resided in the Saline Valley, or *Ko'ongkatün* in the Timbisha language. The Saline Valley was prized by some Euroamerican settlers for its high-quality salt deposits which they first encountered in the mid-1800s. Because of its remote location surrounded by tall, rugged mountains, early efforts to remove salt via horse drawn carriage were unsuccessful. The settlers hired indigenous men from the village of Ko'on located in the valley to construct a road over the Inyo Mountains and later to construct a tramway that went up and over the range. After the tramway was constructed, indigenous workers from the Owens Valley also commuted via the tram to work the Saline Valley salt fields, a treacherous journey during high winds. Through this period, the Timbisha Hunter and Caesar families continued to operate homesteads on the floor of the valley near the salt mine, growing wheat, barley, onions, pumpkins,

SAVE DEATH VALLEY'S FIRST PEOPLE
THE VANISHING NATIVES
TIMBISHA SHOSHONE TRIBE

cabbage, and more. Eventually, these farms were abandoned due to conflicts over indigenous water rights with developers from Los Angeles, not long after the city had drained Owens Lake to supply the LA aqueduct.

Indeed, the early 20th century was a period of removal and dispossession for the Timbisha Shoshone as a whole. The federal government lied about their knowledge of permanent Timbisha settlements to avoid recognizing the tribe, leaving them with no legal recourse after their homeland was declared uninhabited and under federal ownership. The hunting, foraging, and management practices that the Timbisha had relied on for generations were banned within Death Valley National Monument. Visitors who saw the Timbisha village near Furnace Creek decried what they saw as “squalid” living conditions, and the villagers were forcibly moved to a “colony” built the federal government out of view of tourists. This site consisted of eleven bare adobe houses which lacked plumbing and were poorly maintained. Employment was denied to Timbisha men, forcing most to leave. By the mid-1950s, the village had deteriorated badly, and the park service began demolishing homes that appeared abandoned. Some Timbisha families that traveled to the high country in the summer returned to find their homes destroyed, forcing others to remain in their homes to avoid eviction. The park service expected that the eventual death of the tribe’s elders would force the rest of the Timbisha to leave, but some of their descendants refused to vacate their ancestral home.

Activism from the remaining tribe members led them to gain federal recognition in 1983, but the tribe remained landless. In 1996, the tribe organized a protest in Furnace Creek which drew international attention, leading to the 2000 Timbisha Shoshone Homeland Act. The law transferred 7,753 acres to the tribe, including ~300 acres near Furnace Creek and the remaining acreage outside of the national park. The act also established special-use areas within the park, including one for mesquite harvesting and two at Wildrose and Hunter Mountain where the Timbisha are permitted to establish seasonal high elevation camps. Disputes continue between the remaining Timisha Shoshone and the National Park Service over restrictions on traditional land use.

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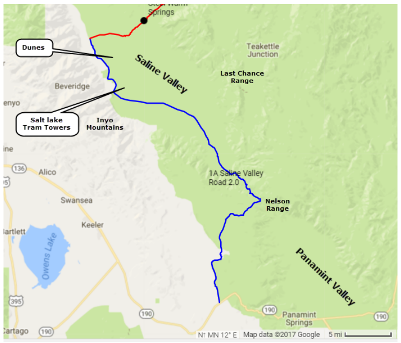
5.18 (18) Salt, Salt Tram and Borax Mining in Saline Valley

Salt, Salt Tram and Borax Mining in Saline Valley

Tejas Oke (G2 Math)

Saline Valley

Saline Valley lies in eastern California within the Basin and Range Province, a region shaped by Cenozoic crustal extension. The valley is a fault-bounded, north–south–trending basin situated between the Inyo Mountains to the east and the Nelson Range to the west. Normal faulting has produced steep mountain fronts and significant relief between the valley floor and surrounding ranges. Saline Valley is an internally drained (endorheic) basin with no surface outlet, causing runoff and groundwater to accumulate on the valley floor.

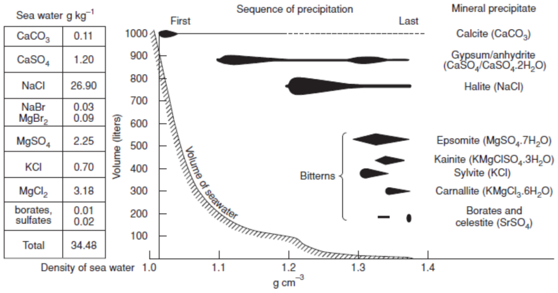

Springs
Dunes
Saline Valley
Teakettle Junction
Last Chance Range
Beveridge
Salt lake Tram Towers
Inyo Mountains
Alico
1A Saline Valley Road 2.0
Nelson Range
Swansea
Keeler
Owens Lake
Panamint Valley
Panamint Springs
136
395
190
N↑ MN 12° E
Map data ©2017 Google
5 mi

Location

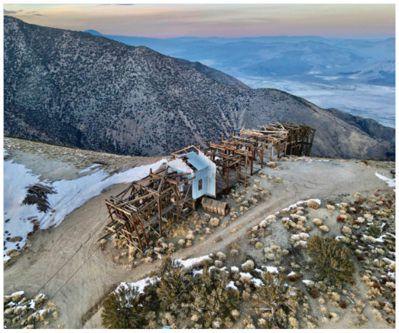
Why salt here?

Runoff and groundwater from the surrounding mountain ranges transport dissolved ions into the valley, where water has no outlet and is lost primarily through evaporation. Repeated evaporation concentrates these dissolved salts, causing evaporite minerals to precipitate on the playa surface. Over long timescales, this process leads to thick salt-rich deposits on the valley floor. Typical evaporite minerals in closed arid basins include chlorides (halite), sulfates (gypsum, anhydrite), and borates (borax, ulexite, colemanite), which precipitate sequentially as evaporation progresses.

Salt tram tower flipped by a desperate tourist in 2024.



Left: Sequence of evaporation for different minerals. (Source: EVAPORITE SALT DEPOSITS By Hassan Harraz October 2015 DOI:10.13140/RG.2.1.3231.3203)



Salt tram summit station.

Borax

Borax mining.

Borax was an important industrial mineral in the late 19th and early 20th centuries because of its wide range of applications. It was used in glass (pyrex glass!) and ceramic production, as a flux in metallurgy, and as a key ingredient in soaps and detergents. Borax also lowered melting temperatures in industrial processes, making manufacturing more efficient and less energy-intensive. Because of this demand, borax deposits in arid basins like Saline Valley became economically valuable despite their remote locations. The Conn and Trudo Borax Company mined borax from the salt marsh from 1874 to 1895.

Salt Tram

The Saline Valley Salt Tram was constructed between 1911 and 1913 to transport borax and salt from the remote valley floor across the Inyo Mountains to rail connections in Owens Valley. The tram was approximately 13 miles long and used gravity to carry loaded buckets downhill while bringing supplies uphill. Its route and design were strongly controlled by the steep, fault-generated relief of the Basin and Range topography. Although technologically innovative, the tram was costly to maintain and operated for only a few years.

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5.19 (19) Sonic Sands

Rodion Zaytsev

Sonic Sands

Introduction

Some desert sand dunes produce a sustained, low-frequency sound when sand avalanches down their slip face. This phenomenon, often called *booming* or *singing dunes*, has been reported for centuries and has attracted scientific attention because of its surprising coherence: millions of individual sand grains moving randomly somehow generate a well-defined musical tone. Modern research frames booming dunes as a problem in granular physics rather than geology or acoustics alone.

The sound typically occurs during steady avalanches on the steep face of large dunes and has a characteristic frequency (70-110Hz).

Observational Characteristics

This low-frequency sound at 70-110Hz can last for tens of seconds or longer while the avalanche continues. Higher-frequency “squeaking” sounds may also occur in disturbed sand, but the sustained booming tone is associated with large, steady flows of sand down the dune face.

The sound emission is not limited to natural dunes. Laboratory experiments have reproduced similar acoustic emissions in controlled shear flows of sand without any dune structure. This suggests that the key mechanism lies in the dynamics of granular flow rather than resonance of the dune as a whole.

Grain Size and Material Requirements

Booming dunes are composed of well-sorted aeolian sand. The grain diameter must be between 0.15-0.3mm. Typical booming sands have mean grain diameters around 0.15-0.2mm and a narrow size distribution. The grains are also clean, rounded and polished. Grain shape and cleanliness matter because they influence friction and collision dynamics. Rounded grains with minimal dust or clay coatings allow consistent contact interactions, which helps produce coherent sound. Moisture also plays a crucial role. Booming occurs only when the surface sand layer is sufficiently dry. Even small amounts of humidity can damp grain motion and suppress sound emission.

Threshold Conditions

There is also a threshold avalanche thickness above which booming occurs.

References:

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5.20 (20) Red Cathedral Formation

Red Cathedral Formation Geology

Winter 2026 GE136 | Maia Hannahs

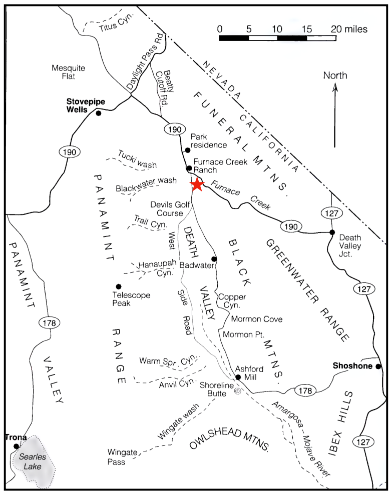
Titus Cyn.
Daylight Pass Rd.
Beatty Cutoff Rd.
Mesquite Flat
Stovepipe Wells
190
NEVADA CALIFORNIA
FUNERAL MTNS
0 5 10 15 20 miles
North
Park residence
Furnace Creek Ranch
Tucki wash
Blackwater wash
Furnace Creek
Devils Golf Course
Trail Cyn.
PANAMINT RANGE
DEATH VALLEY
West Side Road
BLACK MTNS
GREENWATER RANGE
127
Death Valley Jct.
Badwater
Hanaupah Cyn.
Telescope Peak
Copper Cyn.
Mormon Cove
Mormon Pt.
PANAMINT VALLEY
178
Warm Spr. Cyn.
Anvil Cyn.
Ashford Mill
Shoreline Butte
Shoshone
Wingate wash
OWLSHEAD MTNS
Amargosa - Mojave River
IBEX HILLS
Trona
Searles Lake
Wingate Pass

Figure 1: Location of Red Cathedral formation (Sharp, 1997)

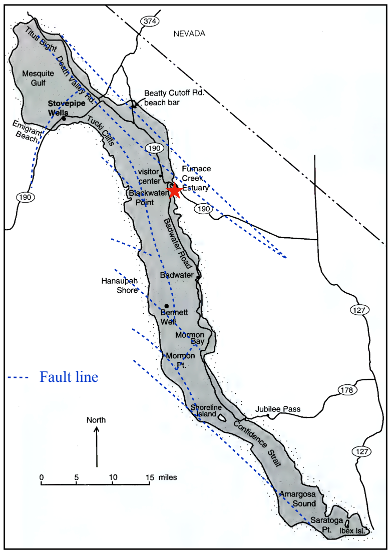
374
NEVADA
Titus Bight
Death Valley Fjd.
Mesquite Gulf
Stovepipe Wells
Beatty Cutoff Rd. beach bar
Emigrant Beach
Tucki Cliffs
190
visitor center
Furnace Creek Estuary
Blackwater Point
Badwater Road
Badwater
Hanaupah Shore
Bennett Well
Mormon Bay
Mormon Pt.
127
Fault line
178
Jubilee Pass
Shoreline Island
Confidence Strait
North
0 5 10 15 miles
Amargosa Sound
Saratoga Pt.
Ibex Isl.

Figure 2: Approximate area of Lake Manly with same location marked (Sharp, 1997) The names are proposed by Sharp as possible features of this past lake.

The Red Cathedral formation is a weathered sandstone outcrop located at the north end of the black mountains just south of the north intersection of I-90 and Badwater road. This is viewable in the distance from Zabriskie point looking north-west and rests at the end of Golden Canyon as part of the Black Mountain range.

The Black Mountains are part of strike-slip fault system which slides past the neighboring plate. The valley between is a pull-apart basin between two large faults such that as these two plates move past each other, the basin opens by thinning of the crust. (Sharp,1997) The Red Cathedral formation lies at the mid-western edge of Black mountains, near the convergence of the Furnace creek fault and the death valley fault. These faults contribute to the rising of the surrounding mountains and the sinking of the death valley floor due to the “stretching” of the crust between the fault lines. This one of the reasons for the geological complexity of the region as the thinning crust leads to the increased volcanic activity of the area. The debris of the volcanic activity can be found in gravels across the region.

The low altitude of the valley caused by these faults was what allowed the valley to be a lake in the early Pleistocene. This body of water which existed 10,000 ago is referred to as “Lake Manly.” As the water level of the basin and the surrounding valleys were filled periodically to different degrees, this is a bit of a generalized term for bodies of water in the basin, as defined between the Panamint Mountain range on the west and the Black and Funeral Mountains on the east. (Knott, 2012) A approximate sketch of Lake Manly is included in figure 2 to show the size and location relative to the red cathedral formation. The faults are shown in blue dotted lines (Hunt, 1966). This would have been the largest of the lakes in the surrounding systems. Evidence of the lake exists in the carbonate tufa along the feet of the mountains, rounded basalt pebbles, and wave carved terraces which exist along the eastern edge, visible near copper canyon, 15 miles south and in the foothills about 8 miles north of the red cathedral formation sits.(Curry, 1954) The floor of the valley is made of the collection of these lake sediments and therefore is practically impervious to water.

The rock surrounding the Red Cathedral formation is a fine silty yellowish sandstone. These come from Pleistocene alluvial deposits as part of the Furnace Creek formation which includes a large alluvial fan. This is a formation made from deposits run off from the black mountains and it relatively “young” in that these alluvial fans would have deposited along the shores of Lake Manly

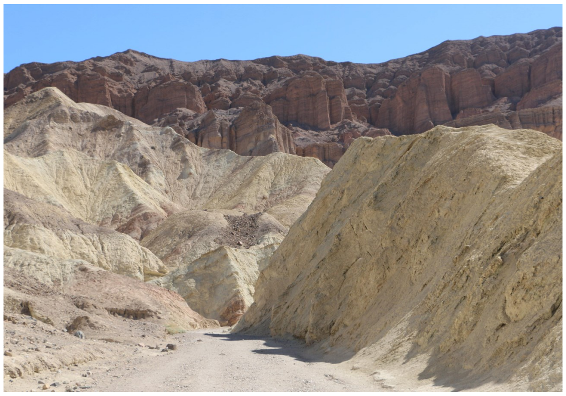

Figure 3: Harder sandstone of Red Cathedral formation rising out of softer sand stone surroundings demonstrating the effects of erosion on rocks of differing hardnesses (Golden Canyon Hike)

within the last 10,000 years. (Sharp 1997) Fans form to a certain spread and depth determined by the flow characteristic of the silt, the velocity of the fluid carrying it and the prevalent weather. The metric used to describe the geometry of settling of fine particles due to gravitational forces is the "Angle of Repose." Much of the alluvial fans of the valley were formed recently enough they can be recognized clearly and have not be lost to further erosion. These fans having a wide and flat lack bed to spread out in are distinctly noticeable as "toes" off the Back Mountain range. (Curry, 1954 notes the age, Sharp is responsible for the term "toes" to describe this) However, if an established fan is subsequently tilted relative to the angel of repose for its initial formation, then further erosion will cut new paths of erosion based on the change in gravitational forces. The combination of the alluvial deposits shifted due to fault lines is noted by Sharp (1997) in descriptions of scarp faults along the furnace creek formation. The downward tilting of the Furnace Creek deposit to the east allowed for the formation of several small canyons cut into the fine alluvial silt along the western edge of the black mountain formation. These cayons reside along Badwater Road, Golden canyon being the one at the north end containing the Red Cathedral formation.

The surrounding alluvial silt which makes up the fan is very soft and easily eroded, consisting mostly of mud stone. The stone of the Red Cathedral formation itself is a denser sandstone, making it more resistant to erosion. Thus the uplifting of the western side of the valley in conjunction with weathering away the softer stone exposed the red sand stone, and shaped it through further weathering. Oxidation of freshly exposed iron ores is likely the cause of the red color. (Golden Canyon Hike)

Golden Canyon appears on park guides as early as 1933, and there are historical brochures which reference Red Cathedral as a named formation on the historical material of the park website. However it is unclear when that became a recognizable named formation as compared to the "colorful rocks" at the base of Zabriskie point.(Park Archives) Now it is recognized as a notable feature of Death Valley national park with a well described hiking trail and markers as a popular tourist destination. (Golden Canyon: Trail Guide)

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5.21 (21) Scotty's Castle

Death Valley Scotty and Scotty's Castle history

Koki Yoshioka

Imagine a $30 million (in today's value) beautiful Spanish style castle [1] in middle of nowhere—or one of the hottest places on Earth [2]—which is named after and was resided by a scammer who did not even pay a nickel for it. This is a short essay on this mysterious mansion and a bizare "friendship" between a con man and a millionaire.

Who is Walter Scott, a.k.a. Death Valley Scotty (DVS)?

In short, he is a smooth-talking scammer (from what I've gathered from Internet). He was born in Cynthiana, Kentucky in 1872 [3]. At the age of 11, he joined the Wild West Show and engaged in show business for 12 years [3]. Then for some good reason, he quits the job and proceeds to pursue a new profession—scammer. He fabricated a non-existing goldmine and gathered thousands of dollars from investors. After his patron has invested more than $5,000 in the goldmine [1], Scott boarded a train bound for New York with "supposedly" full of gold. He claimed that the bag had been stolen before he reached his destination, which was enthusiastically covered in newspapers [1]. This incident made him recognize the power of media in self-promotion. In 1905, DVS suddenly announced that he would break the cross-country train speed record [1] (I found myself somewhat perplexed, as I was uncertain about the depth and significance of the statement. A contemporary equivalent, I would suggest, would be an unknown individual publicly declaring on X that they have invented a state-of-art rocket with takeoff & landing ability). He indeed managed to break the record by 9 hours as promised (44 hours and 54 minutes from LA to Chicago [1]) with his "Scott Special" consisting of an engine, a baggage car, a sleeper, and a dining car [1]. The only passengers were DVS and his wife Jack, and a writer of the LA Examiner [1]. This stunt covered the front page of national newspapers and made his nickname "Death Valley Scotty" widely known (Figure 1). On March 11, 1906, DVS played in "Scott" which opened in Seattle, with him playing the main role, himself [1].

Albert M. Johnson, a successful investor from Chicago, was one of his victims. Upon being noticed about a number of calamities that prevented the delivery of gold and receiving zero results from him, he decides to take a look at the goldmine as one should, only to discover that it did not exist. You would imagine it's the end of it all, but here's where it gets stranger—Johnson did not sue him, rather initiated funding his life—*But why?*

What is Scotty's castle?

Johnson was drawn to DVS's silver tongue. Surprisingly Johnson enjoyed the stay and the personal tour of Death Valley by DVS and DVS somehow managed to keep him interested in his nonexistent "mine". Afterall, he was charmful and funny. The two soon initiates a lifelong friendship. Johnson, who was scammed by this man, starts providing financial support for DVS and his family. DVS once again started spreading "his unbelievable tales about his mines" [1], which Johnson did not interfere regarding them as entertainment

[1]. This interesting relationship gives birth to the fabulous mansion mentioned in the beginning. In 1922, Johnson purchases a property in Death Valley (which turns out to be a government property in the later years [1]) and starts constructing an enormous vacation home what will later be called a “Scotty’s Castle”. This mansion is a two-story Spanish Colonial Revival style villa with an estimated cost of $1.5 million – $2.5 million [4] (around $30 million in today’s value) (Figure 1). It is famously unfished because during the construction, the Great Depression hits the world causing Johnson to lose a significant amount of his fortune and halts the construction before completion [4]. Yet, the mansion was architecturally well constructed enough to be a winter vacation home and a tourist attraction. DVS constantly lived in this house and was instrumental in producing the money out of this property with his great story telling skill. Hence, the name Scotty’s Castle, even though it is not his (nor a castle). After the death of Johnson, DVS was taken care of by the charity established by Johnson [4]. In 1954, DVS passed away.

Scotty’s Castle is allegedly haunted [5]. Some of you might know this from the TV show “Ghost Adventures” (according to reddit, it is regarded as one of the worst episodes in the series). The allegation makes sense because if I were a ghost I would absolutely decide to live in this gorgeous mansion even at the cost of having ghost roommates. In 2015, a flood has destroyed some parts of Scotty’s Castle [6], and a repairing operation has been launched.

Conclusion

The story of Death Valley Scotty is truly bizarre and intriguing. I think that Scotty’s Castle is a reminder of how emotion matters for human beings.

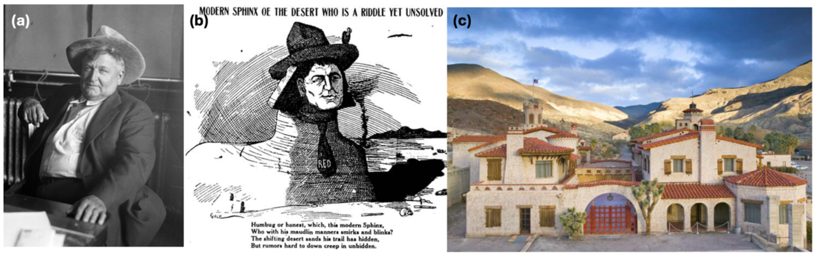
(a)
(b)
MODERN SPHINX OF THE DESERT WHO IS A RIDDLE YET UNSOLVED
RED
GALE
Humbug or honest, which, this modern Sphinx,
Who with his maudlin manners smirks and blinks?
The shifting desert sands his trail has hidden,
But rumors hard to down creep in unbidden.
(c)

Figure 1. (a) An image of DVS, (b) Newspaper cartoon of DVS around 1905, (c) Scotty’s Castle [1,4].

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5.22 (22) Racetrack Playa and Sliding Rocks

Racetrack Playa & Sliding Rocks

Becky Williams Ge136b Winter 2026

The Mystery

Racetrack Playa is a dry lakebed ("playa") famous for its hundreds of mysterious sliding rocks, which leave trails in the mud (see Figure 1). The playa measures 4.5 km long and 2.1 km wide, and is at 1130 meters elevation [6]. The first published report of sliding rocks dates back to 1948 [1], and rocks can go several years up to a decade without moving. The infrequency of movement, combined with the remote location of the playa, make the phenomenon difficult to study, and for a long time scientists could not figure out how the rocks were leaving trails.

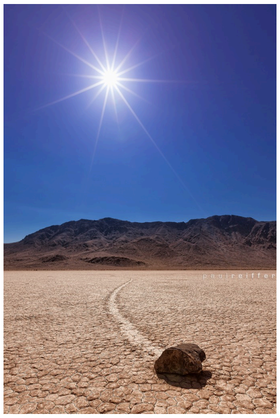

Figure 1: Image of a sliding rock at Racetrack Playa [2].

Initial theories

It was well agreed upon that the rocks likely needed a wet surface and wind in order to move. Exactly how the combination of water + wind caused rock movement was debated. Theories, along with evidence for and against, included:

Hypothesis 1: Rocks are moved by wind

- Running an aircraft propeller over the playa showed that winds greater than 20 m/s could move rocks on a wet surface [3].
- Algal films could lower the friction of the surface, allowing rocks to move at lower wind velocities [3].
- Towing rocks across a mud surface suggested wind velocities of 33-45 m/s necessary for rocks to slide [4].

Hypothesis 2: Rocks are moved by ice

- Rocks that were far apart from each other had parallel tracks, suggesting rocks frozen into the same ice sheet moved together [5].
- Corralling rocks by surrounding them with a ring stakes to test whether the rocks would move in the absence of ice. One rock stayed in the corral, and one exited the corral, suggesting ice is not the driving force [6].
- A later study tracing the rock trails suggested rocks move independently (not with a single ice sheet) [7].

2014: Mystery Solved (?)

In 2011, Norris et al. [8] set out to uncover the mystery of the sliding rocks. They installed time lapse cameras, a weather station (measuring wind speed, temperature, insolation, and rainfall), and 15 rocks with GPS trackers on them. And they waited. Given that rocks can remain motionless for up to a decade, they were not sure how long they would have to wait to capture the phenomenon. Fortunately, they did not have to wait too long: from November 2013 to February 2014, they recorded four rock movement events, and came up with the following explanation.

Heavy rainfall forms a lake in part of the playa, deep enough to partially (but not fully) submerge the rocks. Cold temperatures freeze the top layer of the lake, and then a sunny day breaks up the ice into large ice sheets. Sustained winds of 3.0-4.5 m/s push the water (and ice sheets) and these ice sheets push the rocks across the muddy lake bottom. Eventually, in spring (if not sooner) the lake dries up, revealing new rock trails.

The limiting ingredient in this phenomenon is heavy rainfall, which is rare for the region. The temperatures and wind conditions necessary for rock movement are common in the area. Amazingly, the ice sheets are only a few millimeters thick, but 10s of meters in extent. The rocks slide, rather than roll, along the lake, moving as fast as 2-5 meters per minute, which means you could see them moving in real time if you happened to be there at the right time. Rock movement occurs at mid-day, after there has been sufficient time for the sun to partially melt ice. Rocks do not move for very long, either; the longest recorded rock movement was for 16 minutes. One rock in the study moved as much as 224 meters.

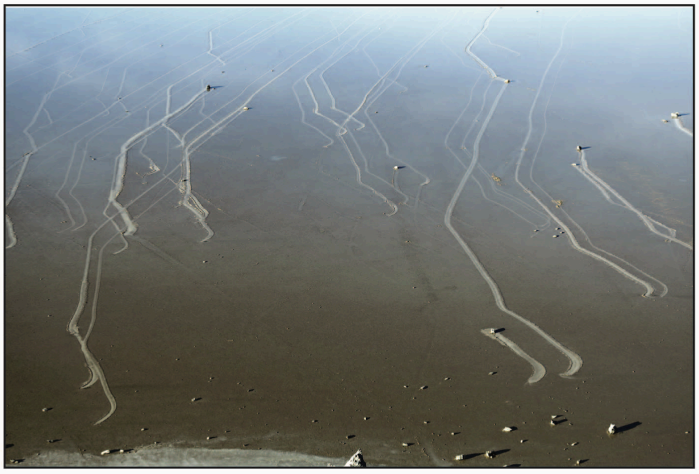

Figure 2: Freshly-exposed rock trails, which show congruent patterns [8].

Remaining questions

Norris et al. [8] showed that the ice sheets can cause rocks to move, but is this the only method by which the rocks move? The authors did not observe any of the large rocks moving, suggesting that something else might be causing movement of the largest rocks. In addition, the other proposed method, wind movement, cannot be entirely ruled out. Jones & Hooke [9] recount the experience of the first author, who claims to have observed, with his own eyes, rocks moving by wind alone over the wet playa: "The time was 1972 or 1973 and the month was probably April or May…During the night, the wind came up more strongly…RJ estimated that the wind speed was likely 25-35 m/s…At about midnight curiosity drove RJ to venture out onto the playa with a flashlight…Finally, after reaching the area of the playa with scattered rocks, RJ watched several move, leaving tracks commensurate with their weight." While not implausible, given previous studies and calculations [3, 4], the author did not have a way of documenting the movement, so take his recollection with a grain of salt. After all, this is Death Valley, famous for its salt flats.

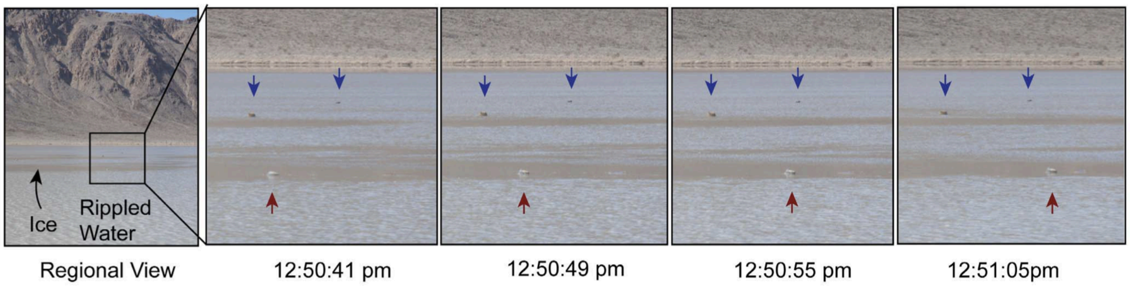

Figure 3: Timelapse images showing the rock in the foreground (red arrow) moving over the span of about 18 seconds [8].

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— Stovepipe Wells Campground: Night 2 —

5.23 (23) Observable Constellations

Observable Constellations - Tryston Raecke - Ge 136b, Geology Field Report

Introduction

The night sky is home to stories that have defined the human experience for time immemorial. This report outlines the northern winter sky primarily through a series of notable Winter constellations in the northern hemisphere that are visible from Death Valley national park. Figure 1 is provided to the reader for help orienting on the night sky.

The Hunter, Orion (Visible until midnight)

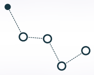
A bright enough constellation to be seen near many urban centers, Orion, is easily recognizable by his "belt" made up of three stars. Beside the left most star is the Orion nebula, a stellar nursery that helps define the sword or knife of Orion, the hunter. He stands holding either a club and shield, or a drawn bow, depending on interpretation. His shoulder is defined by the infamous Betelgeuse, a red supergiant that may "soon" (on the scale of 100,000 years) produce a supernova as bright as the full moon, and his foot by Rigel, a blue supergiant (EarthSky 2026).

In Greek tradition, Orion was a great hunter who claimed he would kill every animal on Earth, provoking Gaia, primordial goddess of Earth, to send Scorpio to kill him with a venomous sting. In honor of their battle, Scorpio and Orion were placed on opposite sides of the night sky with Scorpio eternally chasing Orion (Hyginus 1960; Ridpath 2018). A related tradition exists in many cultures including the Ancient Egyptians, Wiradjuri, Navajo, and Babylonians that sometimes reduced the figure to the three belt stars (Krupp 2003).

Canis Major is Orion's hunting companion, symbolizing the long relationship between humans and dogs. Canis Major is recognized by the bright star Sirius (the brightest in the night sky) (Können et al. 2015) in the center of its collar. In ancient Egypt, Sirius, the dog star, dips below the horizon cyclically with the seasons. When the star appeared on the horizon, it was thought to be a second Sun that could heat up Earth and produce the hottest part of the summer ahead of the flooding of the Nile. Hence, the middle of the Summer, is still colloquially referred to as the "dog days" (Parker 1974; Krupp 2003).

Also associated with Orion are Pleiades and Taurus. Pleiades is a prominent star cluster, while Taurus contains the bright orange Aldebaran and Hyades cluster. In Greek mythology, Pleiades, or the seven sisters, are being chased by Orion. Zeus, to protect the sisters, places Taurus, the bull between them on the night sky (Apollodorus 1921; Eratosthenes 1997).

While this larger story takes a common form across cultures, it may be the oldest story in human history. Today, many people can only account for six stars in the famed "seven sisters". However, approximately 100,000 years ago, when populations of humans had not migrated off the continent of Africa, two of the stars, Pleione and Atlas, were much further apart. It was possible that this is when the name was created and the oral tradition was passed through generations of travelers in the time since. As the two stars moved closer together in the night sky, multiple cultures created similar stories that one of the sisters was lost or dimmed (d'Huy and Berezkin 2017; Kristen Banks 2024).



The Queen, Casseiopeia

Cassiopeia is a distinctive circumpolar constellation, meaning that it always remains above the horizon, above ~34° N latitude. Recognized by five zig-zag stars, The Queen Cassiopeia of Ethiopia was married to King Cepheus and mother to the princess Andromeda. According to Greek Mythology, Cassieopeia was a vain ruler and claimed that she was more beautiful than the sea nymphs. This angered Poseidon, the god of the sea, so he sent a series of floods and a sea monster, Cetus, to destroy the kingdom. Upon consulting an oracle, Cassiopeia and Cepheus were directed to sacrifice their daughter to Cetus to end their struggle. Andromeda is thusly chained to a rock by the sea but finally rescued when Perseus kills Cetus. Not satisfied with the punishment, Poseidon placed Cassiopeia in the sky to circle on a throne forever (Ovid 2008; Hyginus 1960). The region around Cassiopeia contains each of these figures, excluding Poseidon, immortalizing the story on the night sky.

Within Andromeda, is the Andromeda Galaxy, faintly visible under very dark skies without an optical aid. The Andromeda Galaxy is the nearest large galaxy to our own, the furthest object visible without aids, and eventual impact object of the Milky Way (Cowen 2012).

Ursa Major and the Seasons

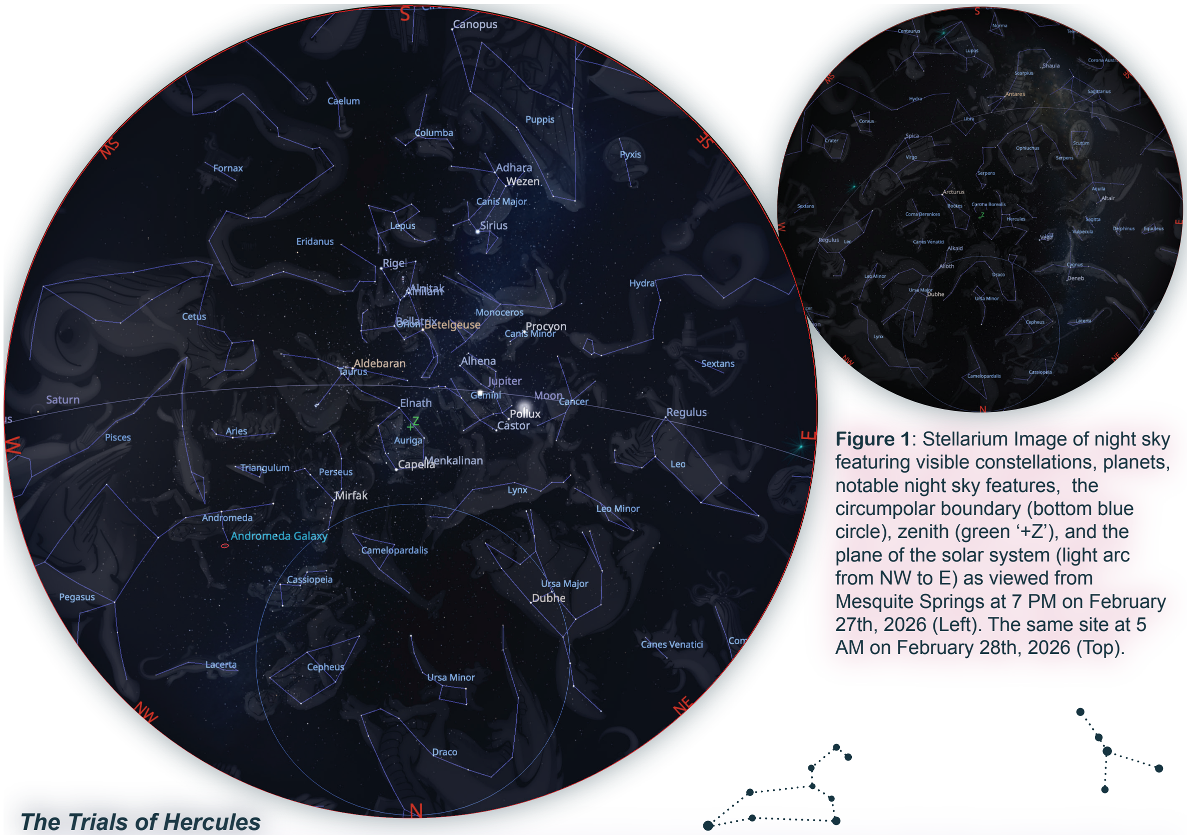
Ursa Major, associated with the asterism "The Big Dipper", is a common feature recognized in the night sky. In both cases, the big dipper is a helpful tool to orient on the night sky, as the two stars at the end of the "dipper", most notably Dubhe, point towards Polaris, the north star, in Ursa Minor.

In Iroquois tradition, Ursa Major is distinctly connected with the seasons. Due to its location at the edge of the circumpolar circle, it dips below the horizon cyclically. In the spring, it is waking up from its den, before being immediately chased by three hunters. As the year progresses, the bear is chased high across the sky at dusk. Eventually, in fall, the bear heads back towards the horizon, when it is said to be killed by the hunters, Robin, Chickadee, and Moose. It is the blood from the slain bear that colors the leaves as the seasons change and the bear hibernates in its den. At the beginning of a new year, a new bear emerges from its den in the spring, and the chase continues once more (Krupp 2003; Williamson 1987; STARLAB® Native American Mythology Cylinder, n.d.).

Ursa Major and Ursa Minor are both said to be chased across the sky by Boötes, sometimes referred to as a shepherd. Boötes is signified by Arcturus, a bright red giant. Within the body of Boötes and far outside our galaxy lies a region known as Boötes' void, one of the largest voids in the known universe with a radius of over 62 Mpc (or 330 million light years across) (Kirshner et al. 1981).

The Twins, Gemini

Directly above Orion are the twins Castor and Pollux, together the Gemini constellation. They are characterized by the two bright stars that make up their heads, the bright white Castor and orange Pollux. (Notably, Castor is actually a set of three gravitationally bound binaries!) (Matvienko et al. 2015). In Greek mythology, Castor and Pollux were two brothers born to different fathers. Pollux, son of Zeus, was immortal, while Castor was not. Together, they sailed on the ship Argos in the story of the Golden Fleece. When Castor was slain in battle, Pollux begged Zeus to share his immortality with his brother. Zeus then placed them both together in the sky, in an eternal embrace. In Roman mythology, they are instead identified as Hercules and Apollo (Hyginus 1960; Apollodorus 1921).


S
Canopus
Caelum
Columba
Puppis
Pyxis
SW
SE
Fornax
Adhara
Wezen
Canis Major
Lepus
Sirius
Eridanus
Rigel
Alnitak
Alnilam
Hydra
Cetus
Bellatrix
Orion
Betelgeuse
Monoceros
Procyon
Canis Minor
Aldebaran
Taurus
Alhena
Sextans
Jupiter
Gemini
Moon
Cancer
Saturn
Elnath
Pollux
Castor
Regulus
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Pisces
Aries
+Z
Auriga
E
Capella
Menkalinan
Leo
Triangulum
Perseus
Lynx
Mirfak
Leo Minor
Andromeda
Andromeda Galaxy
Camelopardalis
Cassiopeia
Ursa Major
Pegasus
Dubhe
Canes Venatici
Lacerta
Cepheus
Ursa Minor
NW
NE
Draco
N

Figure 1: Stellarium Image of night sky featuring visible constellations, planets, notable night sky features, the circumpolar boundary (bottom blue circle), zenith (green '+Z'), and the plane of the solar system (light arc from NW to E) as viewed from Mesquite Springs at 7 PM on February 27th, 2026 (Left). The same site at 5 AM on February 28th, 2026 (Top).

The Trials of Hercules

The twelve labors of Hercules are marked on the night sky in the forms of Leo (the Nemean Lion), Hydra (the Lernaean Hydra), and Cancer (the Crab, Carcinus). Leo is recognized by the "Sickle" asterism, marked with the bright blue star, Regulus. Ahead of Leo is Cancer, seen as a dim upside down "Y". Just beneath this Y is the head of Hydra.

In Greek mythology, the first of Hercules' labors was to face the Nemean lion with impenetrable fur. Hercules instead used brute force to kill the lion and take its coat as armor. The second labor was to face the Lernaean Hydra, a beast with many heads. During this battle, the Carcinus was sent by Hera to help the Hydra defeat Hercules by clamping on his foot. Hercules crushed Carcinus under his heel before calling on his nephew to sever the heads of the Hydra (Apollodorus 1921; Hyginus 1960).

Notable Features in The Night sky

Jupiter can be seen in the center of Gemini throughout the night while Saturn is only briefly visible to the West after Sunset (setting at around 7:26 pm). Venus and Mercury both set around 6:42 pm.

The Milky Way is visible from Death Valley as a diffuse cloud of light and dark spots strewn across the night sky. In the winter, our view is oriented outward through the outer rim. The features seen are less dramatic than those seen during the summer, when the core of the Milky Way comes into view (Binney and Merrifield 1998).

A unique site from a dark sky zone this time of year is zodiacal light. Commonly confused for the milky way, zodiacal light is the sunlight scattered off interplanetary dust in the disk of our solar system. It forms a line across the ecliptic and is most visible in late winter in the northern hemisphere. By eye, it appears as a diffuse triangle extending off the western horizon (Leinert et al. 1998).

Unfortunately, on February 27th, the moon will be in waning Gibbous and will not set until the early morning, around 5:10 am. As a result, many dim features may not be visible by the naked eye outside of a narrow ~20-minute window before the sun rises.

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5.24 (24) Tungsten and Darwin, CA

Tungsten and Darwin, CA

Paolo Sanchez | Ge 136b | Winter 2026

The area of the White-Inyo Ranges and associated mountains of Eastern California is home to not only a vast and varied geological and ecological landscape, but also a mineralogical one. Deposits known as skarns host a wide diversity of mineral species and important metal ores. The abundance of these deposits in California owes itself to the geology of the state. Large slabs of metasedimentary rock, mainly carbonates from the Paleozoic, are commonly associated with igneous intrusions of Mesozoic age across the eastern Sierras and other ranges of eastern California. These form roof pendants that cap some of the tallest mountains in the continental United States, but also represent aureoles, where contact metamorphism and metasomatism of the "country rock" (i.e., Paleozoic carbonates) produce calc-silicate rocks. The process of contact metamorphism often mobilizes gold, silver and tungsten from the country rock and/or the igneous intrusion in hydrothermal fluids that can permeate the country rock, forming a new suite of minerals for skarn deposits.

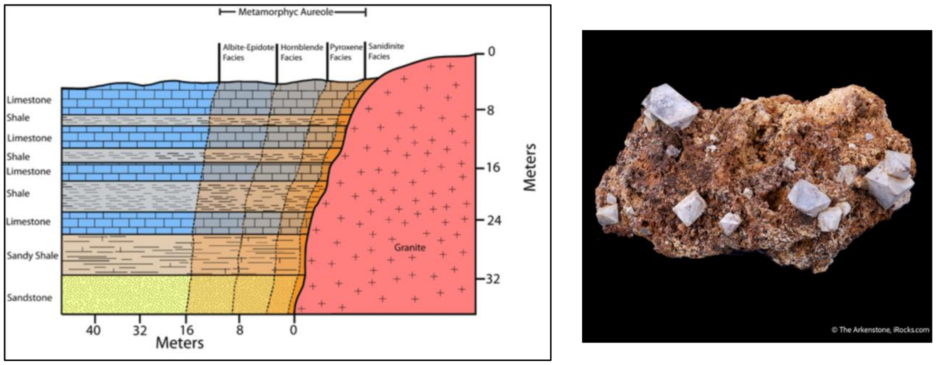

Figure 1: a) Schematic of contact metamorphism of sedimentary country rock with an igneous intrusion. b) Gray crystals of the tungsten ore stolzite ($Pb(WO_4)$) pseudomorphed after scheelite from Darwin, CA.

The Mineralogy Tungsten:

Tungsten has its many uses as a high-density refractory metal, most notably for tungsten filaments of incandescent lightbulbs, for dense tungsten steels for armory and projectiles, and for the compound tungsten carbide (WC). Thus far, there are 52 known minerals with tungsten as an essential stoichiometric component. Geochemically, tungsten typically occurs in the W^{6+} oxidation state and is thus often bonded to make the tungstate ($[WO_4]^{2-}$) anion in a tetrahedral coordination.

Fun fact: Scheelite fluoresces a brilliant blue under shortwave (~255nm) ultraviolet light! Prospectors used this property to find scheelite deposits with UV lights at night. No doubt lots of scorpions were also found!

Scheelite, $Ca(WO_4)$: Stoichiometrically, pure scheelite is 63.85 weight percent tungsten, making it the principal ore of the metal. It was originally discovered in the 1700's and named after Swedish chemist Carl Wilhelm Scheele. Known for its distinct dipyramidal crystals and significant density (6.1 g/cm3), chemically pure scheelite is colorless, but can also be colored orange and yellow due to the presence of trace neodymium and praseodymium.

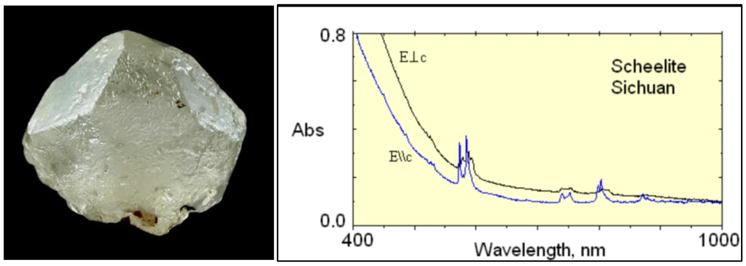

Figure 2: a) Gemmy colorless crystal of scheelite from Kern Co., CA. b) Optical absorption band of a yellow-orange scheelite crystal from Sichuan, China (GRR website).

Wolframite ((Fe, Mn)WO_4): Usually an admixture between the two endmembers ferberite ($FeWO_4$) and hübnerite ($MnWO_4$), it likely alludes to the name given to a froth formed from the smelting of tin ores containing tungsten. It often occurs in high-temperature hydrothermal veins, granitic pegmatites and in alluvial deposits.

Other tungsten minerals: Rarely, tungsten also occurs in more reduced environments such as certain hydrothermal systems and in outer space, producing strange and rare minerals such as tungstenite (WS_2) and catamarcaite (Cu_6GeWS_8). Natural grains of tungsten carbide, known as qusongite, have been reported in alluvial deposits in Japan, and native tungsten metal have even been discovered in the Luna-24 landing site on the Moon.

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Fun fact: The town of Atolia in Kern County was one of the largest producers of scheelite in the world, accounting for nearly 90% of North America's production from 1904 – 1950.

Darwin & California's Tungsten Rush:

In the late 1800s and early 1900s, prospectors came across deposits of tungsten as more of a nuisance than a discovery as they often encountered dense tungstate minerals when separating gold and silver ores. As demand grew for tungsten steel alloys in WWI and WWII, the mining districts for tungsten sprang up all over eastern California. The first deposits were alluvial and vast and were thus easy to mine. Later hard rock deposits such as in the Tungsten Hills and in the settlement of Scheelite, California (literally) were extensively mined.

Although the old mining town of Darwin, south of the Saline Valley, produced mainly gold, silver and lead, tungsten was also mined in the early half of the 20th century. The twenty mines that operated in the Darwin area mined mainly vein and irregular replacement type deposits, often hosted in silicified limestone skarns. The district has produced over $29 million in lead, zinc, silver, tungsten and copper from the 1870s to the 1990s. In 1877, the population of Darwin grew to over 3,500. Today, most of the mines are closed off and Darwin's population has dwindled to around 35 people.

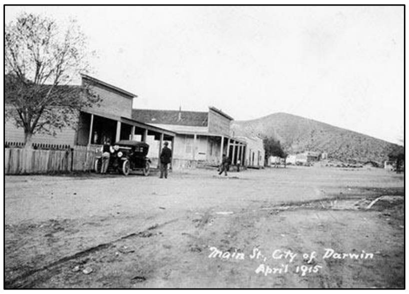

Figure 3: Picture of downtown Darwin, CA, in April 1915.

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5.25 (25) Geochemistry in Searles Valley

Fun Geochemistry in Searles Valley

Forrest McCann

What is an Endorheic Basin?

An endorheic basin (also known as a closed basin) is a basin that prevents water from reaching the ocean. While some water may seep into the ground, it primarily exits the system through evaporation. The water level is dictated by the steady-state balance between inflow and evaporation. Endorheic basins in arid regions often remain dry. Because there is no external outlet, these basins accumulate sediment and dissolved minerals, frequently resulting in salt flats or saline lakes. This accumulation effect also makes endorheic systems highly sensitive to pollution, as contaminants become increasingly concentrated over time. Searles Valley is one of many salt flats/salt lakes within the endorheic Great Basin.

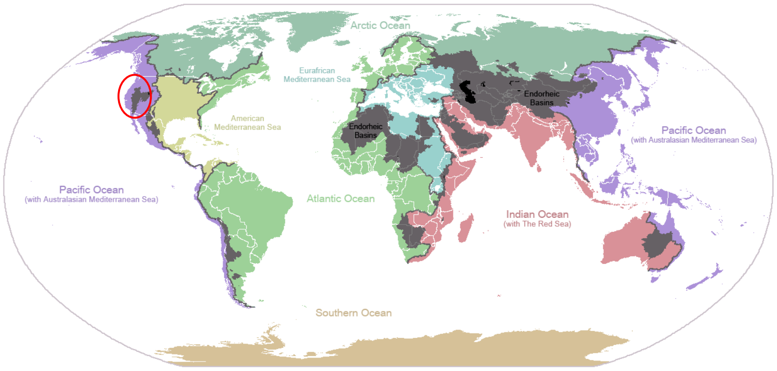

Arctic Ocean
Eurafrican Mediterranean Sea
American Mediterranean Sea
Endorheic Basins
Endorheic Basins
Pacific Ocean (with Australasian Mediterranean Sea)
Pacific Ocean (with Australasian Mediterranean Sea)
Atlantic Ocean
Indian Ocean (with The Red Sea)
Southern Ocean

Figure 1. Map of endorheic basins worldwide. Circled in red is the Great Basin, which contains Searles Valley.

Trona the Mineral: $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$ (sodium sesquicarbonate dihydrate)

Trona is a non-marine evaporite mineral consisting of hydrated sodium carbonate and bicarbonate salts. Precipitating trona requires a low ratio of [Ca^{2+}] to dissolved inorganic carbon (DIC) because calcium carbonate minerals preferentially precipitate and could exhaust available carbonate. Sodium carbonate minerals like trona only begin to form once the calcium in solution is depleted and DIC remains.

Endorheic basins are common globally, but trona is not commonly found in them, raising the question: How does trona form? One hypothesis suggested that the silicate hydrolysis of volcanic rocks or volcaniclastic sediments could naturally produce waters low in calcium and high in sodium necessary for trona. However, many endorheic basins have low calcium volcanic lithologies but do not have trona formation within them. Earman *et al.*[1] looked at the chemical groundwater evolution of major dissolved species in the San Bernardino basin (a place where trona forms) and adjacent basins (no trona formation) to demonstrate that lithology alone could not explain trona formation. The groundwater evolution measurements in San Bernadino Basin indicated that silicate hydrolysis is not the sole process controlling DIC and that injections of volcanic CO_2 are acting to control DIC (high He isotope R/R_a values to corroborate CO_2 source)[1]. The excess CO_2 distinguishes the San Bernardino basin from its neighbors and Earman *et al.* concluded the excess CO_2 is a pre-condition for trona formations. Earman *et al.* also noted that excess CO_2 does not have to explicitly be volcanic in origin and hypothesized that the trona in the Green River Formation (largest trona deposit in the world) could have sourced CO_2 from respiration of organic material. For Searles Lake, a combination of modelling and stratigraphy evidence suggests that CO_2 rich waters were sourced episodically from the Long Valley Caldera and can explain why trona formed in the valley[1].

Figure 2. Trona mineral (left) and Trona frog (right).

Hurricane Hilary (2023) caused Searles Lake and Owens Lake to flood and brought lots of brine into adjacent wetlands and floodplains. The brines killed most of the wetland wildlife and the floods also washed much wetland material into floodplains. The floodplains experienced quick evaporation which allowed for the rapid preservation of frogs in the evaporative minerals. You can find rare examples of "Trona Frogs" from 2023 that are selling for $1,200 out of the Houston Museum of Natural Science[2].

Potash and Soda Ash

Trona is mined globally because it is a good source of "soda ash" (sodium carbonate). Its sister, "pot ash" (potassium carbonate) is also mined in Trona. Both get their name because historically these chemicals were produced by burning certain plants, soaking the ashes in water, filtering the water, then evaporating the water to get the salts. Today, you can either mine advantageous minerals such as trona as a source of sodium (or potassium) carbonate or rely on engineered methods of production using more common inputs (e.g. Leblanc process which requires sodium chloride, sulfuric acid, coal, calcium carbonate or the Solvay process which requires sodium chloride, calcium carbonate, and ammonia).

Trona Pinnacles

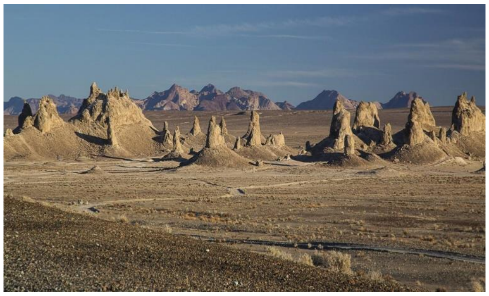


Figure 4. The northern most group of the Trona Pinnacles.

The Trona Pinnacles are a collection of about 500 calcium carbonate pinnacles on the south end of Searles Lake[3]. The pinnacles are in three groups that correspond to their age of formation (north, middle, south and 10,000-140,000 yr old)[3]. The proposed mechanism for the tufa formation is "pinnacles were precipitated by algae about the orifices of sublacustrine springs issuing along faults … in the underlying basement rocks"[4]. The idea is that calcium carbonate saturated water move up through faults and oxygenic photosynthesis (and some CO_2 degassing) removes aqueous CO_2 and causes calcium carbonate minerals to precipitate. The lacustrine sediments were also granitic (sourced from the Spangler Hills) and therefore were permeable enough to allow water to flow up through them[3]. Of the many textures recorded in the tufa, they demonstrate morphologies consistent with algae present at formation (about 50-95% of any given pinnacle have organic matter and algae shaped cells)[4]. The evidence for why these pinnacles formed underwater is as follows[4]: 1) Present day, we observe similar algal tufa towers forming underwater. 2) Ostracod valves (shrimp) are found in the tops of the tallest pinnacles. 3) No pinnacles extend above the old Pleistocene lake shorelines. 4) The pinnacles are underlain and flanked by lacustrine sediments.

There are coarse calcite bands that suggest there was some abiotic formation of calcite, likely from CO_2 degassing. One question we can ask is to what extent would calcium carbonate have been deposited without biology present and how would the resulting formation look different?

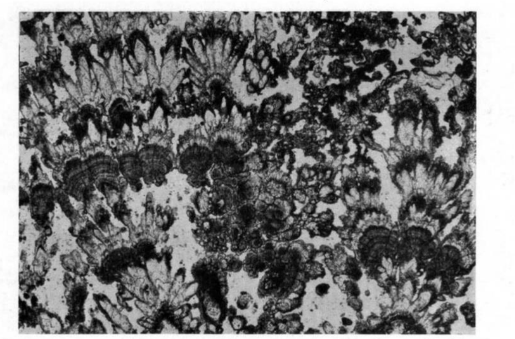
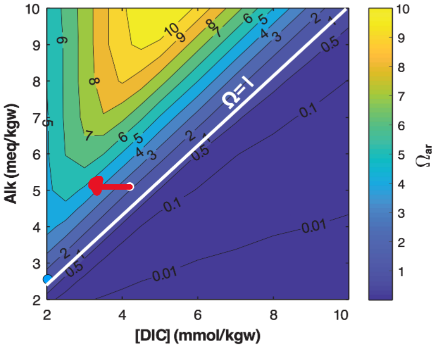


FIG. 5.—Photomicrograph (×24) of dendritic tufa. Dark-colored lobate layers of banded tufa are probably algae secreted, banded calcite laths radiating from these layers may be largely of inorganic origin. Conceivably, the layers represent annual accruements. The oval pigmented bodies near the center of the photograph may be algal cells.



$$\Omega = \frac{[\mathrm{Ca}^{2+}]_{\mathrm{sw}} \times [\mathrm{CO}_3^{2-}]_{\mathrm{sw}}}{K^*_{\mathrm{sp}}}$$

Ω>1 precipitation
Ω<1 dissolution

(1) Earman, S.; Phillips, F. M.; McPherson, B. J. O. L. The Role of "Excess" CO2 in the Formation of Trona Deposits. *Applied Geochemistry* **2005**, *20* (12), 2217–2232. https://doi.org/10.1016/j.apgeochem.2005.08.007.
(2) *Trona after Frog (Petrified)*. Houston Museum of Natural Science. https://museumstore.hmns.org/products/trona-after-frog-2 (accessed 2026-02-21).
(3) Sharp, R. P. (Robert P. *Geology Underfoot in Death Valley and Owens Valley*; Missoula, Mont. : Mountain Press Pub., 1997.
(4) Scholl, D. W. Pleistocene Algal Pinnacles at Searles Lake, California. *Journal of Sedimentary Research* **1960**, *30* (3), 414–431. https://doi.org/10.1306/74D70A51-2B21-11D7-8648000102C1865D.

5.26 (26) Boron Geochemical Cycle

Boron Geochemical Cycle

Ge 136B Field Report

Thang Tran | 2/21/2026

What is Boron?

Boron is a naturally occurring element found within minerals in the Earth's crust [1], denoted using the symbol **B** and the atomic number 5. It is a relatively common element within the crust (ranked 51st), with an average concentration of 8 mg/kg (0.0008%) [1]. When combined with oxygen, the resulting compounds are known as borates, and include boric acid, sodium tetraborates (commonly known as borax), and boric oxide [1]. Boron, through the form of borates, serves as an essential micronutrient for plant growth [2]. In the context of human society, borates are used for a range of goods, including glass and ceramics, soaps and detergents, fire retardants, and pesticides [1].

The Boron Geochemical Cycle

Without human intervention, the main sources of Boron include borosilicate minerals (containing both boric oxide [B_2O_3] and silica [SiO_2]), volcanic eruptions, geothermal and groundwater streams, and sea water [2]. As such, a significant portion of the Boron cycle is directly tied to the water cycle.

Figure 1 demonstrates the concurrency of the Boron and water cycles. First, volcanoes, forest fires, and dust from the soil suspend fine particles, known as aerosols, in the atmosphere. Mixing with rainwater in clouds (wetfall) or as pure particles (dryfall), the Boron is deposited onto both land and sea [3]. Finally, rivers carry the land deposits to the ocean [3].

The ocean also receives a large amount of Boron through the weathering of rock, the absorption of particles in the atmosphere, and from geothermal vents [3]. Groundwater streams and hydrothermal vents carry sediments containing Boron deeper within the Earth's crust [3].

Human Impact on the Boron Cycle

In order to produce the number of goods that require borates, humans directly take Boron from the crust by mining and processing underground minerals [1], as shown in **Figure 1**. The mining and processing of these minerals produces waste, which is dumped into landfills on the Earth's surface, which can leach underground and into the oceans and groundwater streams [2].

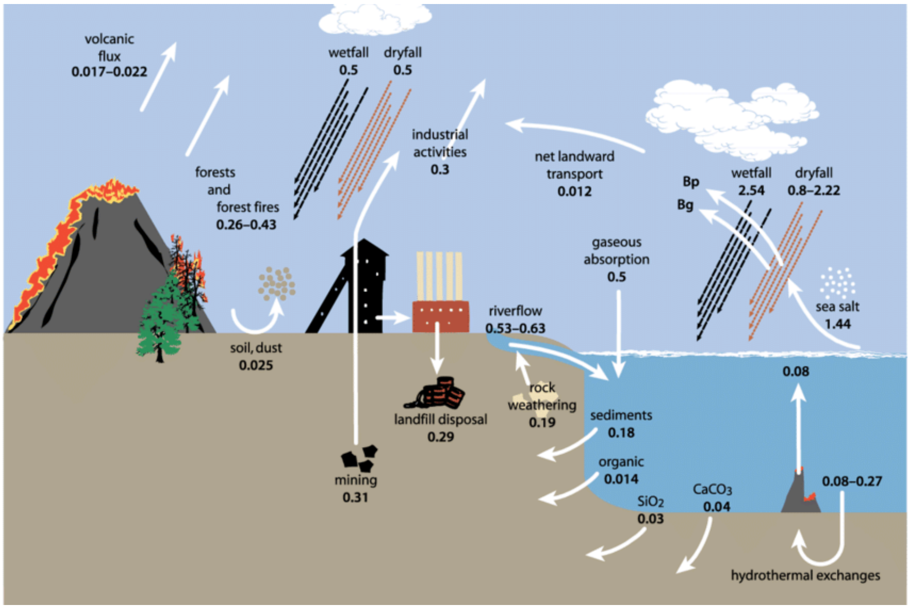

volcanic flux 0.017–0.022
wetfall 0.5
dryfall 0.5
industrial activities 0.3
forests and forest fires 0.26–0.43
net landward transport 0.012
Bp
Bg
wetfall 2.54
dryfall 0.8–2.22
gaseous absorption 0.5
sea salt 1.44
riverflow 0.53–0.63
soil, dust 0.025
landfill disposal 0.29
rock weathering 0.19
sediments 0.18
0.08
organic 0.014
mining 0.31
SiO_2 0.03
$CaCO_3$ 0.04
0.08–0.27
hydrothermal exchanges

Figure 1. *Model of the Boron Geochemical cycle, illustrating both natural and manmade fluxes of Boron within the crust and atmosphere. Values indicate estimated annual Boron fluxes (measured in Tg B yr^{-1}). [Source: 3]*

Other anthropogenic sources of Boron released into the environment include irrigation wastewater and Boron-based fertilizers [2].

Consequences

These unnatural fluxes create higher concentrations of Boron in the crust, which can lead to Boron toxicity in plants and inhibit their growth in arid and semi-arid regions [2]. Additionally, excess Boron intake for humans may be detrimental to the stomach, liver, kidneys and brain, potentially leading to death [2].

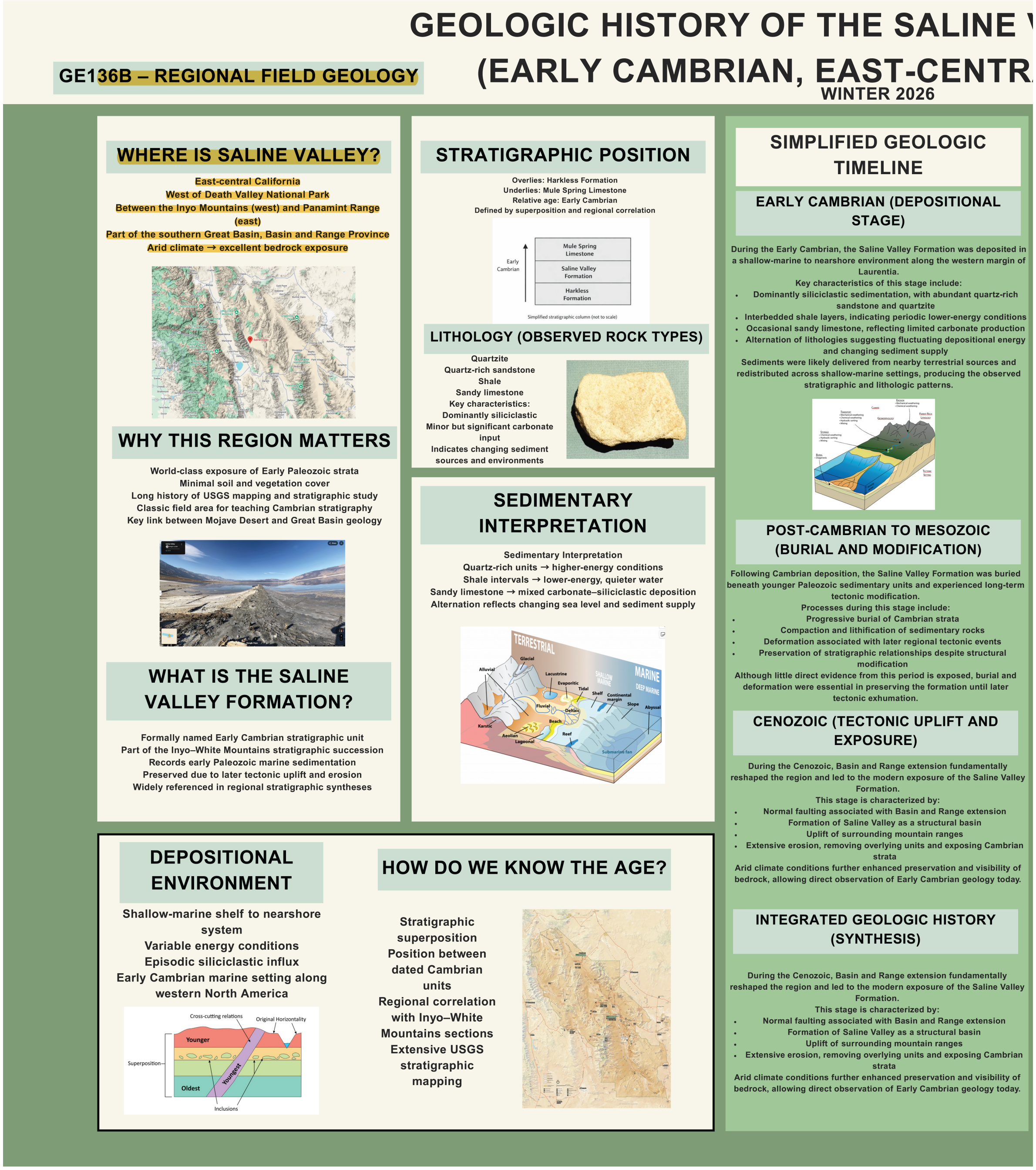
References

[1] *Boron | Public Health Statement | ATSDR*. (n.d.). CDC. https://wwwn.cdc.gov/TSP/PHS/PHS.aspx?phsid=451&toxid=80

[2] Shiv Bolan, et al. *Boron contamination and its risk management in terrestrial and aquatic environmental settings*, Science of The Total Environment, Volume 894, 2023, 164744, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2023.164744.

[3] Park, Haewon & Schlesinger, William. (2002). *Global biochemical cycle of boron*. Global Biogeochemical Cycles. 16. 1072-. 10.1029/2001GB001766.

5.27 (27) Geologic History of the Saline Valley Formation


Early Cambrian
Mule Spring Limestone
Saline Valley Formation
Harkless Formation
Simplified stratigraphic column (not to scale)
Transport
Climate
Erosion
Geomorphology
Parent Rock Lithology
Storage
Burial
Tectonic Setting
TERRESTRIAL
Glacial
Alluvial
Lacustrine
Evaporitic
Tidal
Shelf
Continental margin
Slope
Abyssal
SHALLOW MARINE
MARINE
DEEP MARINE
Fluvial
Deltaic
Beach
Karstic
Aeolian
Lagoonal
Reef
Submarine fan
Cross-cutting relations
Original Horizontality
Younger
Youngest
Superposition
Oldest
Inclusions

GEOLOGIC HISTORY OF THE SALINE V
(EARLY CAMBRIAN, EAST-CENTR

WINTER 2026

GE136B – REGIONAL FIELD GEOLOGY

WHERE IS SALINE VALLEY?

East-central California
West of Death Valley National Park
Between the Inyo Mountains (west) and Panamint Range (east)
Part of the southern Great Basin, Basin and Range Province
Arid climate → excellent bedrock exposure

WHY THIS REGION MATTERS

World-class exposure of Early Paleozoic strata
Minimal soil and vegetation cover
Long history of USGS mapping and stratigraphic study
Classic field area for teaching Cambrian stratigraphy
Key link between Mojave Desert and Great Basin geology

WHAT IS THE SALINE VALLEY FORMATION?

Formally named Early Cambrian stratigraphic unit
Part of the Inyo–White Mountains stratigraphic succession
Records early Paleozoic marine sedimentation
Preserved due to later tectonic uplift and erosion
Widely referenced in regional stratigraphic syntheses

STRATIGRAPHIC POSITION

Overlies: Harkless Formation
Underlies: Mule Spring Limestone
Relative age: Early Cambrian
Defined by superposition and regional correlation

LITHOLOGY (OBSERVED ROCK TYPES)

Quartzite
Quartz-rich sandstone
Shale
Sandy limestone
Key characteristics:
Dominantly siliciclastic
Minor but significant carbonate input
Indicates changing sediment sources and environments

SEDIMENTARY INTERPRETATION

Sedimentary Interpretation
Quartz-rich units → higher-energy conditions
Shale intervals → lower-energy, quieter water
Sandy limestone → mixed carbonate–siliciclastic deposition
Alternation reflects changing sea level and sediment supply

DEPOSITIONAL ENVIRONMENT

Shallow-marine shelf to nearshore system
Variable energy conditions
Episodic siliciclastic influx
Early Cambrian marine setting along western North America

HOW DO WE KNOW THE AGE?

Stratigraphic superposition
Position between dated Cambrian units
Regional correlation with Inyo–White Mountains sections
Extensive USGS stratigraphic mapping

SIMPLIFIED GEOLOGIC TIMELINE

EARLY CAMBRIAN (DEPOSITIONAL STAGE)

During the Early Cambrian, the Saline Valley Formation was deposited in a shallow-marine to nearshore environment along the western margin of Laurentia.

Key characteristics of this stage include:

- Dominantly siliciclastic sedimentation, with abundant quartz-rich sandstone and quartzite
- Interbedded shale layers, indicating periodic lower-energy conditions
- Occasional sandy limestone, reflecting limited carbonate production
- Alternation of lithologies suggesting fluctuating depositional energy and changing sediment supply

Sediments were likely delivered from nearby terrestrial sources and redistributed across shallow-marine settings, producing the observed stratigraphic and lithologic patterns.

POST-CAMBRIAN TO MESOZOIC (BURIAL AND MODIFICATION)

Following Cambrian deposition, the Saline Valley Formation was buried beneath younger Paleozoic sedimentary units and experienced long-term tectonic modification.

Processes during this stage include:

- Progressive burial of Cambrian strata
- Compaction and lithification of sedimentary rocks
- Deformation associated with later regional tectonic events
- Preservation of stratigraphic relationships despite structural modification

Although little direct evidence from this period is exposed, burial and deformation were essential in preserving the formation until later tectonic exhumation.

CENOZOIC (TECTONIC UPLIFT AND EXPOSURE)

During the Cenozoic, Basin and Range extension fundamentally reshaped the region and led to the modern exposure of the Saline Valley Formation.

This stage is characterized by:

- Normal faulting associated with Basin and Range extension
- Formation of Saline Valley as a structural basin
- Uplift of surrounding mountain ranges
- Extensive erosion, removing overlying units and exposing Cambrian strata

Arid climate conditions further enhanced preservation and visibility of bedrock, allowing direct observation of Early Cambrian geology today.

INTEGRATED GEOLOGIC HISTORY (SYNTHESIS)

During the Cenozoic, Basin and Range extension fundamentally reshaped the region and led to the modern exposure of the Saline Valley Formation.

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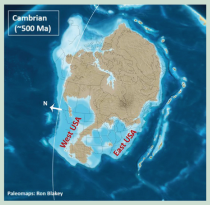
VALLEY FORMATION
AL CALIFORNIA)

YINGYING MA

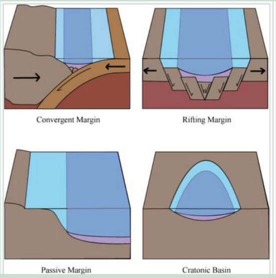
REGIONAL CORRELATION

Correlates with coeval Cambrian units in the Great Basin
Part of a regionally extensive Early Cambrian sedimentary system
Supports broader reconstructions of early Paleozoic paleogeography


Cambrian (~500 Ma)
N
West USA
East USA
Paleomaps: Ron Blakey

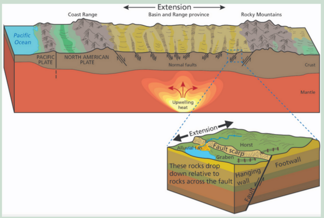
POST-DEPOSITIONAL HISTORY

Burial following Cambrian deposition
Deformation of Paleozoic strata
Long-term tectonic modification prior to Cenozoic extension


Convergent Margin
Rifting Margin
Passive Margin
Cratonic Basin

TECTONIC OVERPRINT

Cenozoic Basin and Range extension
Normal faulting and transtension
Formation of Saline Valley as a structural basin
Uplift of surrounding mountain ranges
Erosion exposes Cambrian strata

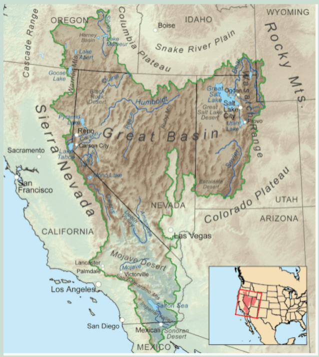

Extension
Coast Range
Basin and Range province
Rocky Mountains
Pacific Ocean
PACIFIC PLATE
NORTH AMERICAN PLATE
Normal faults
Crust
Mantle
Upwelling heat
Extension
Alluvial fan
Fault scarp
Horst
Graben
Footwall
These rocks drop down relative to rocks across the fault
Hanging wall
Fault

WHY ARE CAMBRIAN ROCKS VISIBLE TODAY?

Tectonic uplift raised Paleozoic strata
Arid climate limited vegetation cover
Active erosion removed overlying units
Basin-and-range topography creates deep exposures

BIG PICTURE SIGNIFICANCE

Links Early Cambrian sedimentation to later tectonics
Demonstrates preservation of ancient systems in arid regions
Provides insight into western North America paleogeography
Serves as a classic field example in regional geology


OREGON
IDAHO
WYOMING
Cascade Range
Columbia Plateau
Boise
Snake River Plain
Rocky Mts.
Great Basin
Sierra Nevada
Reno
Sacramento
San Francisco
NEVADA
UTAH
Colorado Plateau
ARIZONA
CALIFORNIA
Las Vegas
Mojave Desert
Los Angeles
San Diego
MEXICO